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Summary report on design, development, and evaluation of intelligent adaptive interfaces for the control of multiple UAVs from an airborne platform

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Technical Report
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Abstract

An absence of guidance on designing complex, dynamic, and networked systems presents challenges to the design of such systems to maximize overall human-machine system performance. An Intelligent Adaptive Interface (IAI) concept and associated technologies have been developed to address this problem. A typical IAI is driven by software agents that can change the display and /or control characteristics to react to the changes of mission and operator states in real time. The work reported here is the result of the two final phases of a three-year project conducted by DRDC Toronto. This project investigated the efficacy of IAIs in a multi-Uninhabited Aerial Vehicle (UAV) scenario. The IAI was modelled as part of the UAV tactical workstations found in a maritime patrol aircraft. In the first phase of the project, a performance model was developed to compare the difference in mission activities with and without IAI agent aids. The simulation results revealed that the control of multiple UAVs is a cognitively complex task with high workload. With the augmentation of automation agents, operators could continue working under high time pressure, resulting in critical tasks being achieved in reduced time. To further test the effectiveness of IAIs and validate the simulation results, a prototype IAI multi-agent experimental environment was implemented for an empirical study. Six IAI agent function groups have been integrated into the UAV operator interfaces. Operator's performance was examined with and without IAIs under three different workload conditions. The results from both objective and subjective measures verified the findings of the simulation research. IAIs facilitated a significant reduction in workload and an improvement in situation awareness. This research also developed preliminary guidance on designing IAI systems.

Résumé

Un problème qui se pose en ce qui concerne la commande de plusieurs engins télépilotés est la gestion de la masse d'informations nécessaires pour appuyer la prise de décision efficace. De l'avis des opérateurs d'engins télépilotés, l'amélioration des interfaces opérateur entraînerait des gains importants au niveau des performances et de l'efficacité des systèmes. Divers niveaux d'automatisation ont été suggérés pour résoudre le problème, dont l'utilisation d'interfaces adaptatives et intelligentes (IAI) pour l'aide à la décision. En dotant les postes de commande des engins télépilotés de groupes de fonctions d'automatisation, les IAI ont pour but de gérer l'information dynamiquement et de fournir la bonne information aux bonnes personnes au bon moment, pour appuyer la prise de décision efficace. Les travaux décrits dans le présent document sont l'aboutissement d'un projet de trois ans, réalisé par R & D pour la défense Canada, portant sur l'efficacité des IAI dans un scénario de commande de plusieurs engins télépilotés dans lequel les IAI sont modélisées comme faisant partie des postes de travail tactiques d'engins télépilotés à bord d'un avion de patrouille maritime. Un modèle de performance a été développé pour comparer la différence entre les activités de mission avec et sans automatisation, différence qui se reflète dans la fréquence des conflits de tâches et le temps d'exécution des tâches. Un prototype d'environnement expérimental d'IAI a été mis en œuvre pour une étude empirique à intervention humaine. Les résultats de la simulation et de l'expérience ont montré que la commande de plusieurs engins télépilotés est une tâche complexe sur le plan cognitif avec charge de travail élevée. Avec l'ajout d'agents d'automatisation, les IAI ont favorisé une baisse appréciable de la charge de travail et une amélioration de la connaissance de la situation. Les opérateurs peuvent continuer à travailler sous de fortes contraintes de temps, et des tâches critiques peuvent être exécutées en moins de temps qu'avec des interfaces classiques.

Executive summary

Intelligent adaptive interfaces: summary report on design, development, and evaluation of intelligent adaptive interfaces for the control of multiple UAVs from an airborne platform

Ming Hou; Kobierski, R.D.; DRDC Toronto TR 2006-292; Defence R&D Canada – Toronto; December 2006.

Introduction: The deployment and control of Uninhabited Aerial Vehicles (UAVs) generate an enormous amount of data that will become even more complex as more communication channels are engaged between air, sea, and ground for joint operations. As the quantity and variety of those data increase, the workload of UAV operators is likely to increase exponentially, imposing severe constraints on personnel conducting these missions. One way to reduce operator demands is to convert data into information and automatically disseminate it to the right decision-makers. Another method is to look for opportunities to limit the complexity of tasks that humans perform when controlling UAVs. A third approach seeks to limit the number of tasks to be performed.

Feedback from UAV operation reports indicates that there is a need for improvement in the operator interfaces of these emerging systems. This applies to effective UAV control and data management, including converting data into information and efficiently disseminating the information to appropriate users. The level of automation (intelligent and adaptive software) applied to the decision-making process is important for tactical commanders and UAV system managers. Thus, supporting technologies such as Intelligent Adaptive Interfaces (IAIs) requires investigation. The work reported here is the result of a three-year project that investigated the efficacy of IAIs in the UAV context. The selected environment involved UAV operations in support of counter-terrorist activities. The IAI was modeled as part of the UAV tactical workstations for a modernized Canadian Maritime Patrol Aircraft CP140. This work was divided into three phases.

Results: Phase I produced a methodology to analyze UAV operations in a mission scenario. The scenario reflected a portion of a Canadian Forces (CF) UAV experimental program. The analytical results were used to develop a human-machine task network model that was then implemented in an integrated performance network modeling environment. The model has two modes for operators to work with user interfaces controlling multiple UAVs. One mode assumed that operators used conventional interfaces to control multiple UAVs. The other mode assumed that operators used interfaces with IAI automation aiding. The difference between mission activities with and without IAI aiding was reflected in the time to complete critical task sequences and task conflict frequency. The simulation revealed that the use of a control interface with IAI mode permitted operators to complete critical task sequences in reduced time, even under high time pressure.

Phase II focused on the design and implementation of IAI prototype interfaces which incorporated six system function groups: inter-crew communications, route planning, routing following, screen management, data-link monitoring, and UAV sensor selection. A synthetic environment was created which followed the North Atlantic Treaty Organization (NATO)

Standardization Agreement (STANAG) 4586 interface software protocol. The experimental environment had three control consoles replicating CP140 tactical compartment workstations, with a set of appropriate displays and controls for each of the UAV crew members: UAV pilot, sensor operator, and tactical navigator. The experimental environment also has an integrated video and audio data collection suite to facilitate empirical assessment of IAI concepts.

In Phase III, experiments were conducted to examine operator workload and interface adaptability with mock-up UAV control consoles. Eight crews (24 operational CP140 members) participated in the experiment. Each crew completed a two-day experiment that assessed operator interfaces with and without IAI aiding. The results showed reduced completion time for critical task sequences in the IAI mode. There was also a significant reduction in workload and an improvement in situation awareness.

Significance: The objective of this project was to demonstrate IAI capabilities in reducing workload and improving operator performance during the deployment of UAVs. Both task network simulation and human-in-the-loop experimental results showed that the use of IAIs in advanced operator interfaces, such as multiple UAV control systems; improved the effectiveness of the crew.

Sommaire

Intelligent adaptive interfaces: Summary report on design, development, and evaluation of intelligent adaptive interfaces for the control of multiple UAVs from an airborne platform

Ming Hou; Kobierski, R.D.; DRDC Toronto TR 2006-292; R & D pour la défense Canada – Toronto; Décembre 2006.

Introduction ou contexte : Le déploiement et la commande d'engins télépilotés génèrent une quantité énorme de données qui deviendront même de plus en plus complexes à mesure que le nombre de canaux de communications air-mer-sol augmentera pour les opérations interarmées. Avec l'accroissement de la quantité et de la variété de ces données, la charge de travail des opérateurs d'engins télépilotés risque de croître exponentiellement, de sorte que de fortes contraintes seront imposées au personnel exécutant les missions. Une façon de réduire les contraintes imposées aux opérateurs consiste à convertir ces données en information pertinente et à la fournir automatiquement aux décideurs pertinents. Une autre consiste à chercher des occasions de limiter la complexité des tâches que les humains accomplissent pour la commande des engins télépilotés. Une troisième consiste à tenter de limiter le nombre de tâches à accomplir.

La rétroaction à la suite des opérations menées avec les engins télépilotés indique qu'il y a lieu d'améliorer les interfaces opérateur de ces nouveaux systèmes, tant en ce qui concerne la commande réelle des engins télépilotés que la gestion des données, y compris la conversion de ces données en information et l'acheminement efficace de cette dernière vers les utilisateurs appropriés. Le niveau d'automatisation (logiciel intelligent et adaptatif) à appliquer aux processus de prise de décision est un facteur clé tant pour les commandants tactiques que pour les gestionnaires de systèmes d'engins télépilotés. Par conséquent, il faut examiner les technologies d'appui (p. ex. l'interface opérateur adaptative et intelligente) qui font appel à la fois aux interventions des opérateurs et à l'automatisation pour satisfaire aux exigences des missions. Les travaux décrits dans le présent document sont l'aboutissement d'un projet de trois ans, réalisé par R & D pour la défense Canada, portant sur l'efficacité d'interfaces adaptatives et intelligentes (IAI) dans une situation opérationnelle. L'environnement sélectionné a donné lieu à des opérations d'engins télépilotés visant à appuyer des activités de lutte contre le terrorisme, l'IAI étant modélisée pour faire partie intégrante des postes de travail tactiques d'engins télépilotés à bord d'un avion de patrouille maritime canadien CP140 modernisé.

Résultats : La première phase du projet sur les IAI a permis d'établir une méthode d'analyse des opérations d'engins télépilotés dans un scénario de mission élaboré de manière à refléter une partie du programme de renseignement, de surveillance et de reconnaissance du littoral atlantique des Forces canadiennes. Les résultats de l'analyse ont été utilisés pour élaborer un modèle de performance qui a ensuite été mis en œuvre dans un environnement de modélisation de réseau de performance intégré. Le modèle a été utilisé dans deux modes : dans le premier, on considérait que les opérateurs utilisaient une interface classique pour commander plusieurs engins télépilotés; dans le second, on considérait que l'automatisation était réalisée à l'aide d'une IAI. La différence entre les activités de mission avec et sans automatisation s'est manifestée dans le temps nécessaire à l'exécution de séquences de tâches critiques et dans d'autres mesures de la

performance. La simulation a montré que l’utilisation d’une console de commande à laquelle un mode IAI est intégré a permis aux opérateurs de continuer à travailler sous de fortes contraintes de temps et d’atteindre les objectifs de niveau supérieur dans un délai réduit.

La deuxième phase était axée sur la conception et la mise en œuvre de prototypes d’IAI intégrant cinq groupes de fonctions d’IAI : communications entre équipages, planification de trajectoire, gestion d’écran, surveillance de liaison de données et sélection de capteurs d’engins télépilotés. On a créé un environnement synthétique conforme au protocole de logiciel d’interface STANAG 4586 de l’OTAN. L’environnement expérimental comprenait trois consoles de commande reproduisant les postes de travail de compartiment tactique du CP140, avec un ensemble d’affichages et de commandes appropriés pour le pilote d’engin télépiloté, l’opérateur de capteurs et le navigateur tactique. Cet environnement permet aussi la vidéo intégrée et la collecte de données audio, de sorte qu’il est possible de faire une évaluation empirique des concepts d’IAI élaborés dans la première phase.

La troisième phase consistait en l’exécution d’expériences visant à examiner la charge de travail des opérateurs, la complexité des tâches et l’adaptabilité d’interface lorsque des consoles de commande de maquettes d’engins télépilotés sont utilisées. Huit équipages (au total 24 membres opérationnels du CP140) ont participé à l’expérience. Chaque équipage a réalisé une expérience de deux jours visant à évaluer subjectivement et objectivement les systèmes de commande avec et sans aide IAI. Les résultats ont montré, dans le mode IAI, une amélioration importante de la performance de l’équipage quant au temps requis pour l’exécution de séquences de tâches critiques; en outre, on a observé une réduction appréciable de la charge de travail et une amélioration de la connaissance de la situation.

Importance : L’objectif du projet consistait à déterminer si les fonctions d’IAI permettraient de réduire la charge de travail et d’améliorer la performance des opérateurs durant le déploiement d’engins télépilotés. Les résultats de la simulation de réseau de tâches et de l’expérience à intervention humaine ont montré que la commande de plusieurs engins télépilotés est une tâche complexe sur le plan cognitif avec charge de travail élevée. On a conclu que l’utilisation d’IAI dans les systèmes d’opérateur avancés, par exemple les systèmes de commande de plusieurs engins télépilotés, présenterait de réelles possibilités d’amélioration de l’efficacité de l’équipage.

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1 Introduction and motivation

A goal for the design of complex, dynamic, and networked systems (e.g., military systems used in network centric warfare) is to maximize overall human-machine system performance. A lack of guidance for designing these systems and their characteristics (e.g., complexity, dynamics, or information overload) generates challenges to achieving this goal. However, advances in human factors engineering, artificial intelligence, and related disciplines provide numerous potentials that can be leveraged for effective design. One advanced interface design concept that attempts to do so is the Intelligent Adaptive Interface (IAI). An IAI is an operator interface that changes the display and/or control characteristics of human-machine systems to react to external events (mission and operator states) in real time. A typical IAI is driven by software agents (automation) that provide aids to satisfy the decision-making and action requirements of operators under different levels of workload. It is designed to present the right information or action sequence proposals, or performs actions, in the right format, and at the right time. Although there are many different definitions of IAI in the literature and many different names (Intelligent User Interface, Maybury, 1998; Intelligent Interface Technology, Benyon, 2000; and User Adaptive Systems, Jameson, 2003), the key element is that an IAI reacts adaptively to the external events including both mission and operator states.

An early concept related to the IAI is the crew adaptive cockpit (Reising, 1979). The goal here was to migrate tasks from operators and help them make tactical and strategic decisions. Operator interface technologies exist in a number of guises, from conventional automation to intelligent adaptive aiding. Conventional automation was designed to replace human control and decision-making. However, due to its nature of being out of the loop of the external events in some situations, it may be difficult for operators to maintain situation awareness (Billings, 1991; Cook, Woods, McColligan, & Howie, 1990; Endsley, 1996; Endsley & Kiris, 1995; Moray, 1986; Norman, 1990) and vigilance (Moray, 1986). It may make it difficult for operators to calibrate the automation' capabilities to the current state (Lee & Moray, 1992; Parasuraman & Mouloua, 1996; Parasuraman, Mouloua, Molly, & Hilburn, 1993). In addition, it may cause loss of skills, over-trust (i.e., complacency), lack of trust (i.e., scepticism), and increased system complexity (Parasuraman, Sheridan, & Wickens, 2000; Sarter & Woods, 1994; Will, 1991), and other problems. On the other hand, adaptive automation offers an alternative design approach to allocate systems functions to automation and a human operator dynamically over time. The relationship between automation and operator should be flexible and context dependent to optimize overall system performance (e.g., Kaber & Riley, 1999; Parasuraman, 1987; Rouse, 1977; Scerbo, 1996).

In contrast to conventional automation, the provision of adaptive automation aiding is not pre-determined at the design stage and the task allocation to human or system is not fixed. Thus, an adaptive automation system is dynamic in nature. The loci of control change by taking advantages of the differences between the abilities of humans and machines. In providing this dynamic or adaptive support, the perceived loss of control with static automation can be reduced as human operator remains “in-the-loop” (e.g., Hilburn, Molloy, Wong, & Parasuraman, 1993; Hilburn, Jorna, Byrne, & Parasuraman, 1997; Kaber, Riley, Tan, & Endsley, 2001; Kaber, Wright, Prinzel, Clamann, 2005; Parasuraman, Mouloua, Molly, & Hilburn, 1993; Scerbo, 1996). However, adaptive automation does introduce more complexity in the allocation of tasks that can result in new problems such as being out of system functional state and automation failure detection. A key design issue is to optimise the triggering conditions for task re-allocation (e.g., by monitoring behaviour, physiological changes, and/or situation events).

At the highest level of maturity, adaptive aiding systems "intelligently" augment and enhance human judgment and responsibility. These systems can adapt to dynamic requirements of external events: both operator and mission states. These adaptive aiding systems can be considered to be "intelligent" as they exhibit behaviours that are consistent with human intelligence (Taylor & Reising, 1998): for example, being goal driven; capable of actively collecting information; capable of reasoning at multiple levels; capable of learning from experience; and capable of context-sensitive communication with the operator (i.e., they are IAIs). The "intelligence" of such IAI systems is derived from a functional architecture that couples real-time mission analysis with real-time monitoring of the psychological, physiological, and behavioural state of the operator. The information from these modules can then be used to mediate the timing, salience, and autonomy operator aids. The functional architecture should have the following attributes: a model of human decision-making and control abilities; the ability to monitor operator performance and workload through behavioural and physiological indices; and the ability to predict operator expectations and intentions with reference to embedded knowledge of mission plans and goals.

There is some empirical evidence supporting the benefits of IAIs. A PACT (Pilot Authorization and Control of Tasks) system uses a system functional architecture to design IAIs to reduce operator workload and increase situation awareness. It is part of the Cognitive Cockpit system (Banbury, Bonner, Dickson, Howells, & Taylor, 1999; Taylor, Bonner, Dickson, Howells, Miller, Milton, Pleydell-Pearce, Shadbolt, Tennison, & Whitecross, 2002) which couples a situation assessment module with a pilot state estimator to drive intelligent adaptable Pilot-Vehicle Interfaces (PVI). The resultant PVI adaptations take the form of readily interpreted information, warning messages, advisory displays and control feedback that allows the pilot to remain in full command of the aircraft. The PACT system also includes the notion of the Rotorcraft Pilot's Associate project (Miller & Hannen, 1998) which took the strategy to migrate tasks from operators to automation agents to improve situation awareness. Another IAI use is a metaphor of controlling automation function in the 'playbook' (Miller, 2000, Miller, 2003; Miller, Goldman, Funk, Wu, & Pate, 2004). In this IAI system, there are a number of 'plays' available to the operator in which the role of the automation and operator for a particular task has been pre-configured (e.g., the system provides advice if authorized by the operator). Although these studies have provided a valuable starting point for prototyping and testing any other IAI systems for the purpose of workload reduction and situation awareness improvement, the Cognitive Cockpit did not provide fully implemented models and the "playbook" challenges the operator's memory and effectively using many "plays" in a time-critical situation. For experimental purpose, there is still a need to identify an experimental technique. The technique will allow for testing of observable IAI functions without a full-scale implementation. For design purpose, there is not any guidance on IAI systems.

In order to address the issues above, Defence Research & Development Canada (DRDC) - Toronto started a multi-year project for the development and evaluation of IAIs for multiple Uninhabited Aerial Vehicle (UAV) control. The aim of the project was not only to design, develop, demonstrate, and prioritize enabling IAI technologies, but also to develop design guidelines for IAI systems. These technologies can be applied to advanced operator interfaces which will support reduced manning and enhanced performance in complex military systems, particularly multiple UAV control from an airborne platform. This project laid the foundation for the production of preliminary design guidelines for IAIs in this context.

IAI technologies should: a) improve human-machine system performance, b) reduce operator workload, and thus c) enhance situation awareness. In order to test these hypotheses, the IAI project was conducted in three phases: IAI concept development, interface prototyping, and experimentation. Phase I of the project involved an analysis of UAV operations in a mission scenario to support counter-terrorism activities. The scenario involved operations with the IAI modeled as part of the UAV tactical workstations of a modernized Canadian CP140 Maritime Patrol Aircraft. In the scenario, the CP140 crew took over the UAV operation in the role of UAV Pilot (UP), UAV Sensor Operator (UO), and Tactical Navigator (TN) in the tactical compartment of the aircraft. The analytical results were used to develop an operator-machine performance model that was implemented in an integrated performance modeling environment. The model has two modes. One mode assumed that operators used conventional interfaces to control multiple UAVs. The other assumed that operators used interfaces with IAI automation aiding. The difference between mission activities with and without IAI aiding was reflected in the time to complete critical task sequences and task conflict frequency. The simulation revealed that the use of a control interface with IAI mode permitted operators to complete critical task sequences in reduced time, even under high time pressure. Hou & Kobierski (2006) and CMC Electronics Inc. (2004) described the simulation work done in the first phase.

This report summarizes Phases II and III of the IAI project. These two phases focused on the design and implementation of IAI prototype interfaces, and on experimentation that investigated IAI efficacy. Further, preliminary design guidelines were developed to guide the IAI system design.

2 IAI Prototype and mission scenario

An experimental Synthetic Environment (SE) was designed and developed using the North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4586 (CDL, 2005) interface software protocol. The SE had three control consoles replicating CP140 tactical compartment multifunction workstations consistent with the UAV crew positions used in Phase I (concept development). The workstations were designed to communicate with virtual UAVs through software interfaces. Each had a set of displays and controls appropriate for the UP, UO, and TN positions. The experimental environment could also collect video and audio data. The experimental protocol was approved by DRDC Human Research Ethics Committee in 2005 (see Annexes A-F).

2.1 Prototype interface layout

The CP 140 Subject Matter Experts (SMEs) noted that in an operational subsystem UAV operators occupy the three rear positions of the CP140 tactical compartment (illustrated in Figure 1). Thus the experimental environment has been designed to match these three positions. The overall configuration included UP, UO, and TN workstations as shown in Figure 2. Each workstation consisted of a display screen, keyboard, Programmable Entry Panel (PEP), trackball/mouse, and joystick (for UP and UO only). The UP and the UO were seated next to each other and shared a console, as illustrated in Figure 3. A shared display screen (i.e., the middle display in Figure 3) was placed between the operators. This display was a modified version of the TN's Tactical Plot (TACPLOT) that showed various contacts and their associated track numbers. With this set-up, the shared display could facilitate communications between UP, UO, and TN within the same contexts.

A TN's primary display is shown in Figure 4, which was designed to communicate tactical information. The TN display illustrated the supervision and management of tactical situations as well as the consistencies with the TN's main role as coordinator of the CP140 UAV crew.

The UP's primary display is shown in Figure 5. This provided the information necessary to pilot UAVs. The basic layout allowed operators to display a mini-TACPLOT and pilot camera view for up to two UAVs. All pilot camera views had Heads-Up-Display (HUD) style symbology (superimposed) to show critical flight data. Since some UAVs do not have a pilot camera, a solid background replaced the pilot camera image, although the same HUD-style symbology was shown.

The UO's primary display is shown in Figure 6. This was designed to allow the UO to manage and extract information from many sensors. Operators could flexibly manipulate the layout of the main display area. Information about the instantaneous direction of the turret with respect to the current UAV heading, sensor elevation angle, and zoom setting was superimposed on the sensor video.

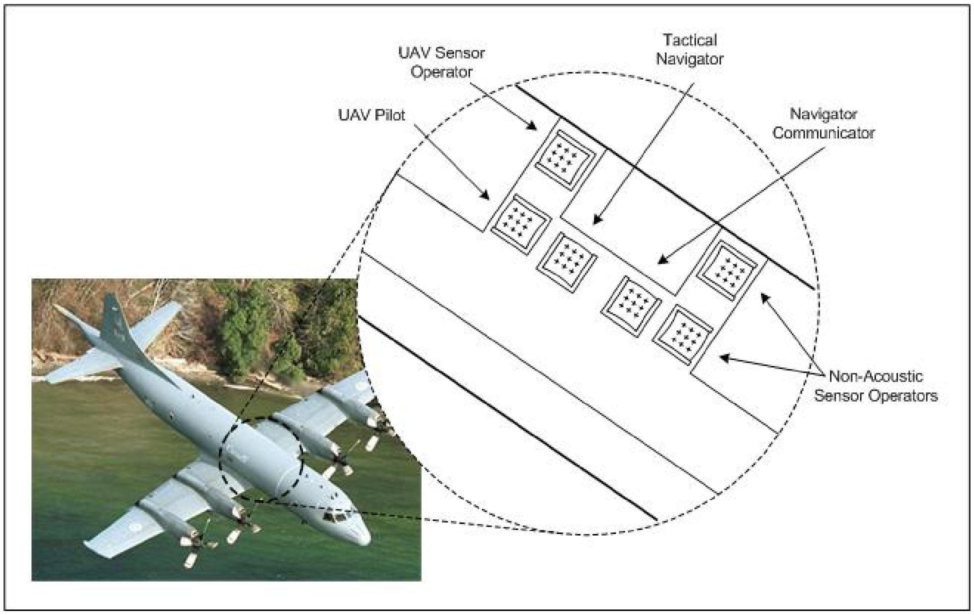

Figure 1: CP140 Tactical compartment layout with Tactical Navigator (TN), UAV Pilot (UP), UAV Sensor Operator (UO), and Navigator Communicator (NAVCOM) positions

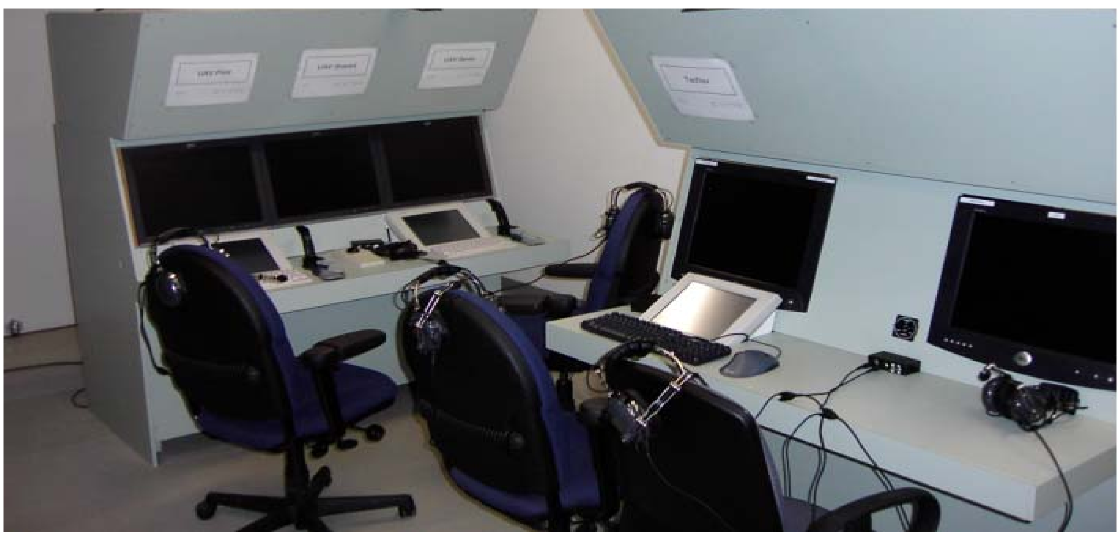

Figure 2: Experimental environment showing three UAV control workstations and NAVCOM workstation (to the right)

Figure 3: UP and UO positioned at the Aft rearward-facing workstations

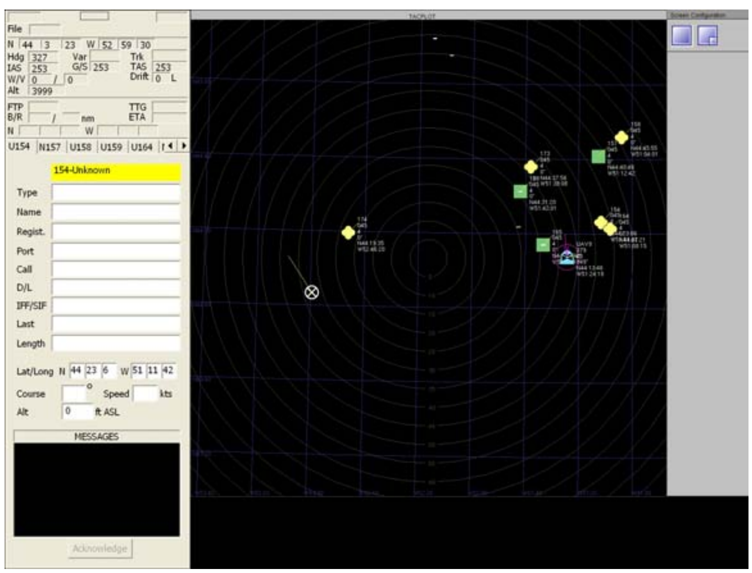

Figure 4:Primary display for TN

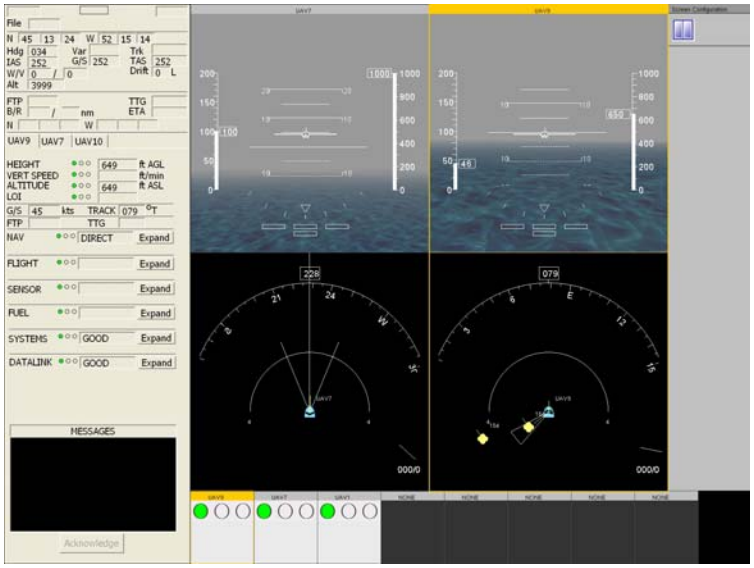

Figure 5*: Primary display for UP*

Figure 6: Primary display for UO

2.2 IAI software

The IAI agents were system functional components of the UAV control SE. They provided decision support to the experimental participants and took over some crew tasks with high workload.

The IAI agents followed this sequence:

- Step 1: Gather status information about all active UAVs, their tracks, and the current display configuration.
- Step 2: Analyse the information with respect to the SMEs' pre-defined rules and determine which events have occurred.
- Step 3: Prioritize the events according to pre-defined rules.
- Step 4: Execute pre-defined tasks for each identified event following the prioritization order.

Depending on the results, IAI agents could actively support the operators in the following tasks identified by the SMEs in this context:

- Task 1: Route Planning. If a UAV was used to investigate an unknown or hostile contact, the agent would compute the most direct route and activate that route for the UAV. The allocation of tracks to UAVs was based on a search for closest unknown or hostile contact. Additional logic ensured that no more than one UAV could be engaged on a single unknown contact. More than one UAV could be engaged on hostile contacts.
- Task 2: Route Following. The agent would pilot the UAV on the active route. This included flight altitude, speed management, and self-preservation in close proximity to the track. The agent entered an orbital flight pattern around the track once the UAV reached sensor identification range.
- Task 3: Screen Management. The shared TACPLOT was agent-managed (according to pre-defined rules) whenever new high-priority events occurred. This included automatically panning the TACPLOT to a location of interest and zooming in or out.
- Task 4: Inter-crew Communications. All observations on UAVs track relationships were reported by the agent to the crew via the IAI message window. Thus, the crew did not need to make or confirm theses observations.
- Task 5: Sensor Management. Once a UAV was close enough to a track to engage an Electrical Optic (EO) sensor, the agent would take over sensor management. This included pointing the sensor and establishing a stable lock on the moving target once the track was within visual range.
- Task 6: Data Link Monitoring. The agent monitored the flight pattern (and other status of the UAV) to determine whether the data link was working. If not, the agent would immediately inform the crew.

Six software agents were designed and implemented in the IAI prototype interfaces as multi-agent subsystems.

To allow agents to communicate events and actions to the crew quickly and reliably, the IAI Graphical User Interface (GUI) showed IAI messages on the primary display. Figure 7 shows an example of an IAI message window used on the operators' primary display. The IAI message window is also shown in the bottom left corner of Figures 4, 5 and 6. The IAI message window shows all active UAVs, allocated tracks, and information about how the IAI agent supported the UAV. On the TACPLOTs, text was added to the UAV icon as illustrated in Figure 8. This identified the contact designated by an IAI agent and whether the agent was exercising UAV flight control (“P”) and/or sensor geotracking (“S”).

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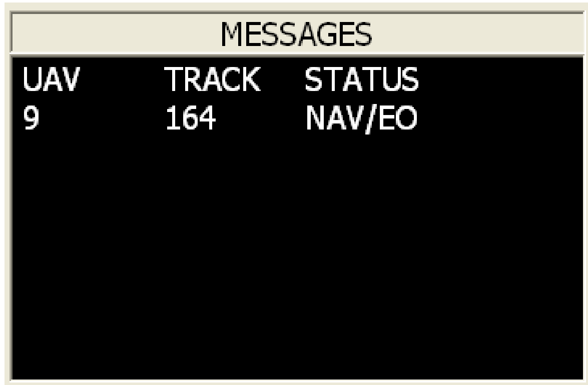

Figure 7: IAI message window

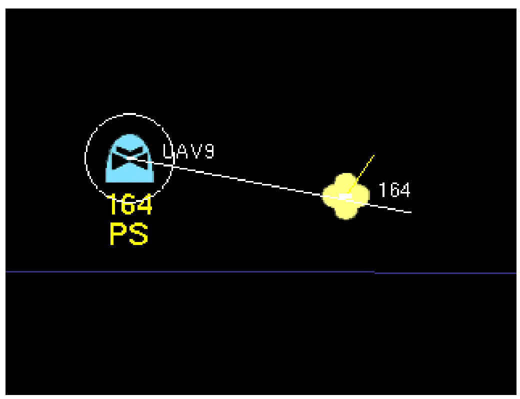

Figure 8: IAI readouts in TACPLOT

2.3 Mission scenario

To evaluate IAI prototype interfaces, a counter-terrorism mission scenario was developed and set in the year 2011. The Commonwealth of Nations had chosen St John’s, Newfoundland as the site for the bi-annual Commonwealth Heads of Government Meeting (CHOGM). The Canadian Forces (CF) was to provide security for the meeting. At 1745 hrs, August 11, 2011, British Intelligence relayed information about a Lethal Medium Range UAV, a potential threat to the CHOGM. This device could be launched from a van-sized steel container. The intelligence groups suspected that the Lethal UAV had been launched from a boat as far as 240 nautical miles (nm) away. The group suspected of fielding the weapon had obtained a quantity of plutonium from a nuclear power plant. A UAV carrying a plutonium “dirty bomb” would cause many casualties and render the targeted region potentially uninhabitable for years.

In the meantime, there was a fisheries patrol southeast of St. John's, and about 200 vessels were in the vicinity of the Grand Banks on the east coast of Canada. The Canadian frigate HMCS Halifax was in the region with two Vertical Take-Off UAVs (VTUAV) and a Maritime Helicopter (MH). A CP140 patrol aircraft equipped with 16 Mini UAVs and a sensor suite was overhead. Figure 9 illustrates the scenario.

The scenario began at 1800 hrs, after the CP140 crew had received information that there was a possible terrorist threat to the CHOGM. The crew was tasked to search for a vessel carrying a launch container (approximately 10 ft x 8 ft x 20 ft). Intelligence reports had suggested that the threat might come from a trawler-sized vessel. The UAV crew was provided with a VTUAV from HMCS Halifax. Once the VTUAV cleared its mother ship, HMCS Halifax made ready and launched the MH. The mission was to investigate a concentration of vessels to the south. The ship's crew knew that recovery of VTUAV 1 would be necessary at approximately the same time that the MH returned. However, this was declared after the VTUAVs and the MH were airborne.

At 1843 hrs, contact was lost with VTUAV 1 as it approached a vessel under investigation. The CP140 launched three Mini UAVs over the contact area and warned other airborne units to avoid the possible threat. The Mini UAVs approached and started to investigate the vessel. At the same time, HMCS Halifax made the best possible speed to the same location. VTUAV 2 was also directed towards the suspicious boat, and its control was passed to the CP140 crew.

At approximately 1850 hrs, a Mini UAV transmitted an image of men working on the trawler's fo'c's'le. A large storage container was exposed. The CP140 used the EO sensor of VTUAV 2 and Mini UAVs to observe. The container was opened to expose a Jet Assist Take-Off UAV. Minutes later, the lethal UAV was launched. Two CF18s were ordered to attack the now identified terrorist boat. Assisted by a laser UAV controlled from the CP140 the terrorist boat was destroyed prior to launching a second lethal UAV. At 1900 hrs, the experimental scenario ended. The CP140 crew initiated a search for the lethal UAV, which was tracking toward St John's.

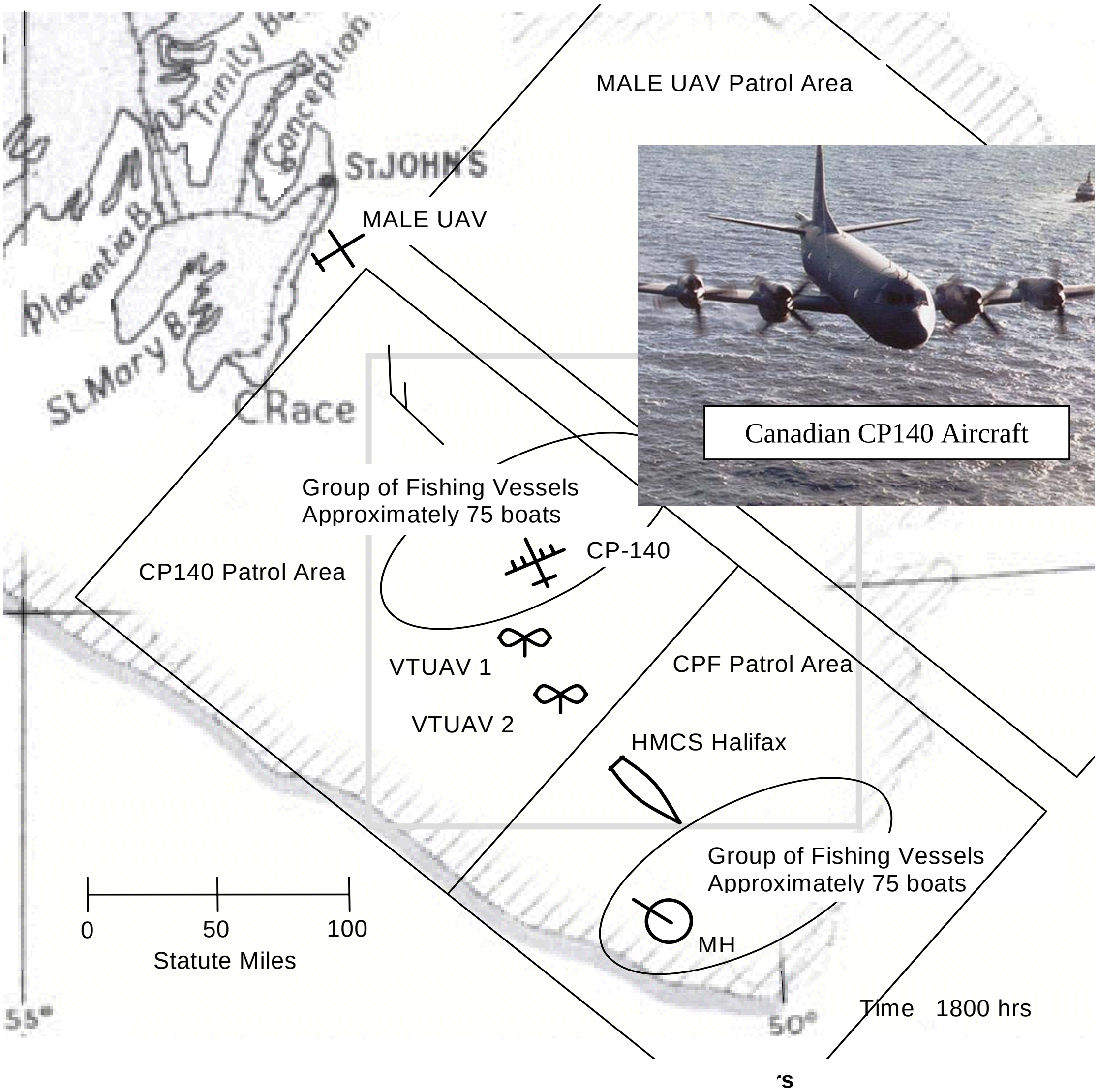

Figure 9: Grand Banks overview at 1800 hrs (MALE implies Medium Altitude Long Endurance)

3 Experimental design

To determine if IAIs reduce operator workload and improve Situation Awareness (SA) and performance, a human-in-the-loop empirical investigation on the efficacy of IAIs was conducted. The IAI multi-agent system supported six IAI tasks as described above in Section 2.2. The evaluation was conducted with two different operator interface modes (IAI features on and off). Besides the interface condition, the other experimental variable was workload which had low, medium, and high levels built in as three parts of the scenario, respectively.

3.1 Participants

The roles of UAV operators as experiment participants were assigned positions as described in Section 2.1:

Tactical Navigator (TN). The TN was the mission commander and responsible for managing the use of all resources to accomplish the mission goals.

UAV Pilot (UP). The UP was responsible the deployment, management, and control of individual UAVs.

UAV Sensor Operator (UO). The UO was responsible for the selection and management of the EO sensors and the interpretation of sensor data.

Eight UAV crews were recruited as volunteers from the CP140 community at the Canadian Forces Bases (CFB) Comox and Greenwood. Each crew had three members taking UAV control positions: UP, UO, and TN. The assignment of roles was based on the amount of experience in the aforementioned positions, with crewmembers being assigned to the position with which they had the most experience. All participants were male, and the age ranged from 26 to 52 years (Mean = 40.1 years). All had operational experience with the CP140, and the experience ranged from half a year (120 flying hours) to 20 years (6300 flying hours) (Mean = 8.2 years or 2679 hours). All participants were “fit to fly” for the experiments in the simulated CP140 tactical compartment. The UAV crews were supplemented by an experimental staff member who played the role of Navigator Communicator (NAVCOM). The NAVCOM’s primary role was to liaise with the experimental staff and the crew (experiment participants). As the experimental scenario unfolded, the NAVCOM communicated to the subject crew (i.e., UP, UO, and TN) the “taskings” from the Maritime Operations Centre (MOC) at Maritime Forces Atlantic, in Halifax.

3.2 Apparatus

The experimental environment consisted of multiple hardware and software components. The major hardware components were:

1. Participants' consoles and physical layout of the experimentation area;

2. Participants’ prototype GUI display; and

3. Integrated video and audio data collection suite.

The experimental environment is depicted in Figure 2. This figure also shows the NAVCOM's position relative to the UP, UO, and TN. The interfaces for these three crewmembers are described in Section 2.1 and illustrated in Figures 3, 4, 5, 6. The TN and the NAVCOM shared a console, but all the scenario details were shown on the NAVCOM's display and therefore were blocked from the TN's line of sight by a physical barrier.

All video data were captured using either Pelco TM high-resolution security cameras or using Extron TM scan converters, which allowed video recording of all participants' monitors. All video data were relayed through a compatible personal computer running Pelco TM security software. They were displayed on a 21" Silicon Graphics Cathode Ray Tube (CRT) monitor. All audio data captured were relayed through an aircraft quality communication system to the Digital Video Recorder. They were linked to each of ten video input channels. There were two audio channels on the communication system. The main channel was the crew channel, on which all parties could hear all participants' communications. The secondary channel was the experimental channel, on which only the experimental staff (including NAVCOM) could hear one another.

The experimental environment had also multiple software components communicating within a Microsoft Windows XP environment. The major software components were:

1. An IAI multi-agent system embedded in the operators' interfaces;

2. A software package that completed data collection of operator keystrokes and vehicle motions;

3. A three-dimensional world through which the UAVs flew and were viewed by the participants through the UAV-mounted video cameras;

4. A software package that simulated rotary wing and fixed wing air vehicle flight dynamics and autonomous surface vehicle (boat) motion; and

5. A NATO STANAG 4586 compatible software that allowed communication between the consoles and the simulated UAVs.

The IAI multi-agent system was a process software component embedded in the Data Management System (DMS) of the UAV IAI SE. When all IAI agents (interface function groups) were switched off (IAI OFF), the interface was simply the conventional interface without the aid of the IAI multi-agent system. When all IAI agents were switched on (IAI ON), the various function groups coded into the interface software were activated. The DMS was the central data processing component of the UAV IAI SE and served as a protocol gateway between the workstations and the external simulation components. Figure 10 illustrates the DMS architecture.

The DMS maintained a synchronized situational data repository of all relevant information related to the UAVs, the CP140 ownership, and the surface and air-borne tracks. The DMS processed and organized pertinent information for efficient consumption by the workstations so that the workstation operators could relay UAV control commands to the simulated UAVs and change workstation display configurations.

All entity motion data were recorded on a Windows XP computer hard drive. This information included time-sequenced player positions to allow post experiment plotting of routes for all entities and a record of all information relayed between the workstation and the vehicle motion simulation software STRIVE®(CAE, 2005).

STRIVE® was modified from controlling one UAV to concurrently controlling multiple UAVs. The control of a number of UAVs and their sensors followed NATO STANAG 4586 standard through the simulated mission computer (with dual or single processor and 32 MB OpenGL graphic cards). The sensor views of the SE relayed through STANAG 4586 were provided to the OP and UO. The visual databases and the entity models were also available to the multi-UAV scenario.

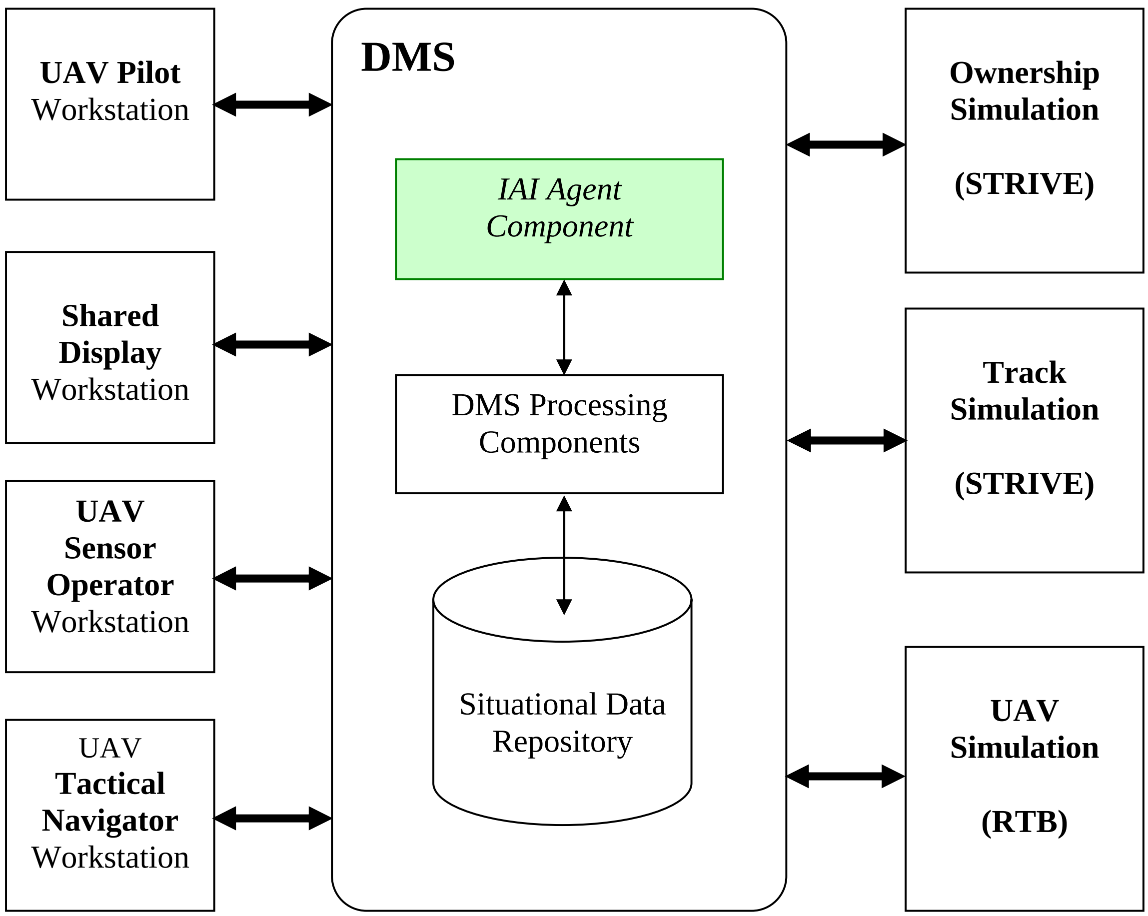

Figure 10: *DMS system architecture and interfaces*

3.3 Independent variables

The effectiveness of the prototype IAI system on aiding operators' performance was examined using a 2 (Interface Condition: IAI ON vs. IAI OFF) x 3 (Operator Workload: Mission Part 1 vs. Mission Part 2 vs. Mission Part 3) repeated measures design. Thus, each participant experienced each of the six experimental conditions created by factorially crossing these two variables.

The two levels of Interface Condition were defined as to whether the crew was using either the standard interface (i.e., IAI OFF) or the standard interface augmented with the IAI multi-agent system (i.e., IAI ON). The IAI for each participant was tailored to suit their needs in the following ways. The UP's IAI provided an automated route planning feature that was able to be activated under certain conditions. The UO's IAI would automatically orient its EO turret such that the closest unknown contact could be seen. The TN's IAI provided a tactical plot that indicated how long it would take each UAV to reach the closest unknown contact. The TACPLOT, which was primarily used by the UP and the UO, would automatically re-centre and re-scale.

The three levels of Operator Workload were built into the three parts of the mission scenario. Part 1 of the scenario was to induce the lowest workload by involving in only one Vertical Takeoff UAV (VTUAV) and only one contact. Part 2 of the scenario was to produce moderate workload. It involved the control of two UAVs (i.e., one VTUAV and one mini UAV) and the task of prosecuting two contacts. Part 3 of the scenario was to induce the highest workload. It involved the control of up to five UAVs (i.e., one VTUAV, three mini UAVs and one laser designator UAV) and the task of prosecuting three contacts while keeping "eyes-on" a fourth contact. Part 3 of the scenario had a higher level of time pressure than Parts 1 and 2 because two CF-18s (not under the control of the UAV crew) were inbound and required timely laser designation of the terrorist vessel.

3.4 Dependent variables

Both objective and subjective measures were used to index each participant's performance under (a) the two levels of IAI condition and (b) the three levels of operator workload condition. There were two subjective measures for the experiment: perceived workload and perceived SA. There were five objective measures: completion time for Critical Task Sequences (CTSs), percentage of CTS shedding, UAV route trajectory score, UAV airspace violation time, and Situation Awareness Global Assessment Technique (SAGAT) score.

3.4.1 Objective measures

Completion Time for CTSs As a primary measure, it was the time in seconds to complete all of the CTSs. The CTSs were defined previously using a Hierarchical Goal Analysis (HGA) conducted in the first phase of the project (Hou & Kobierski, 2006), but were limited to tasks that had objective and clearly observable start and end points. They were further constrained by the scenario itself. The tasks had to be performed by each crew in the same manner so as to avoid excessive variability in the data between the different crews.

Percentage of CTS Shedding This measure was to compliment the CTS completion time measure. It highlights deficiencies in the strategy of quickly and accurately completing only a few critical tasks at the cost of not attending to other critical tasks under high workload conditions. Given that only successfully completed CTSs were included in the completion time analysis, the strategy of shedding tasks would not be captured in these data. That is, crews that adopted this strategy would appear to have performed well because their completion times would have been short. However, their performance might have been poor; depending on the number of tasks they shed (the ones they did not complete). The percentage of CTS shedding measure highlighted the number of incomplete tasks.

The percentage of CTS shed was calculated by dividing the number of valid (i.e., unaffected by extraneous variables) incomplete CTS subsets by the total number of CTS subsets and then multiplying this result by 100. Unlike the CTS task completion time measure, the CTS shedding measure was only calculated for all CTSs and not for CTS subset. It was not necessary to describe this measure in terms of a CTS subset as it was calculated in terms of a percentage. It is therefore not susceptible to the statistical issues associated with (a) an unequal number of CTSs across mission parts and (b) different tasks across mission parts. As with the CTS completion time measure, the CTS task shedding was only analyzed for Parts 2 and 3 of the mission scenario.

Airspace Violation Time The violation time was the frequency with which participants violated (i.e., flew within) a half nm radius surrounding each contact. This “stand-off” zone was briefed as a “no-fly” area and time spent within this area was counted against the crew. The measure is the average amount of time (in seconds) that each crew spent flying their critical UAVs in the half nm radius that surrounded each contact. This measure was to provide a detailed perspective on the crews’ navigational errors by highlighting the temporal magnitude of each airspace violation.

Route Trajectory Score This measure was to assess the effectiveness of the participants to fly the best routes to investigate all potential contact. It was calculated independently for each critical UAV in each of the three mission parts. There was one critical UAV in Part one, two critical UAVs in Part two and four critical UAVs in Part three. These seven critical UAV trajectory scores were calculated for both IAI conditions (ON and OFF), therefore yielding a total of fourteen route trajectory scores for each crew. The route trajectory score for each critical UAV was calculated by determining the average difference in distance between the actual trajectory and the optimal trajectory. As such, a lower route trajectory score indicated better performance. With that in mind, a correction factor was applied to each route trajectory score, which penalized crews for violating a half nm no-fly airspace that surrounded each contact. This correction factor increased the route trajectory score proportionally with the amount of time spent violating the half nm airspace.

SAGAT Score Based on Endsley’s (1995) research, SAGAT is a means to measure SA when operators perform a task. Following completion of each of the six experimental sessions, each participant was asked to re-create their memory for the location, heading, and classification/identification of all contacts within an 80 nm radius of their own location by plotting them on a sheet of 8.5 inch by 11 inch graph paper. The accuracy of these plots was subsequently evaluated by an SME and given a rating of 1 through 10 according to a modified Cooper-Harper rating scale, where a score of 1 indicated excellent SA and 10 indicated very poor SA (Cooper & Harper, 1969).

3.4.2 Subjective measures

Two subjective measures were used to evaluate crew performance, perceived SA and perceived workload. Participants were given a questionnaire at the end of each of the six sessions that asked them to rate their overall SA and their workload. Perceived SA was rated on a seven-point Likert scale where 1 represented "very low" SA and 7 represented "very high" SA. Crewmembers were asked to circle a number from one to seven that they felt represented their average overall SA for that session.

The perceived workload measure was derived from the NASA Task Load Index (TLX) Workload assessment scale (Hart & Staveland, 1988). Participants were asked to rate their workload on a 100-point scale for: Mental Demand, Physical Demand, Temporal Demand, Frustration Level, Effort, and Performance. An important measure derived from the TLX Workload scale is overall workload, which represents a summary of these six workload subscales. One approach would be to average the six subscale scores and use the mean as each crewmember's overall workload. This method, although straightforward, would be misleading given that the relative importance of each of the six subscales is most likely unequal. Hence, weightings were assigned to the six subscales to determine their relative importance using two different methods: the pair-wise comparison technique and the subjective weighting technique. Each member of five of the eight crews and all three NAVCOMs involved in the experiment were asked to provide these relative weighting measures.

The pair-wise comparison technique requested the participants to select which of two subscale measures of workload (e.g., mental demand vs. temporal demand) had a greater influence on the crew during the experiment. Each combination of the six subscales was compared for a total of fifteen comparisons. The responses were tabulated and the rankings were summed to reveal the relative contribution of each workload factor. For the subjective weighting technique, the same respondents were asked to indicate a percentage value for each of the six subscale workload factors that reflected its relative importance to the overall goals of the mission, where 0% was low importance and 100% was high importance. They were further instructed to ensure that these six percentages summed to exactly 100%. These percentage values were then averaged across all eighteen respondents. The results from these two methods for determining relative weights (i.e., pair-wise comparisons and subjective weightings) were then averaged to provide one final weighting value for each of the six subscales of workload. Each TLX subscale workload score was then multiplied by its final weighting value. These products were then summed to yield the overall perceived workload measure.

A separate questionnaire was also given to the NAVCOM after each of the six mission segments where he or she rated the performance of the each participant separately and the performance of the crew as a whole. The NAVCOM was an essential member of the crew in addition to being both a SME and an important experimental staff. These characteristics allowed for a fair, accurate and independent assessment of the crew's performance.

3.5 Mission versions and counterbalancing

Each crew was tested under both IAI ON and OFF conditions under each of the three Operator Workload levels. Each crew experienced each of the three mission parts twice (i.e., ON and

OFF). In order to prevent the influence on the crews' second exposure to a mission part from their first experience with an identical part, the second version of each part was created by rotating the original mission layout to its mirror image. The track identification numbers for each contact were changed in order to increase the disparity between the two versions of the mission. Part 1 always occurred first, once with IAI OFF and once with IAI ON. Part 2 always occurred second, once with IAI OFF and once with IAI ON. Part 3 always occurred last, once with IAI OFF and once with IAI ON. In order to prevent practice effects from contaminating the data (i.e., improved crew performance due to increasing familiarity with the user interface and UAV flight dynamics), Interface Condition was balanced across crews. That is, half of the crews received the IAI OFF condition first and the IAI ON condition second. This order was reversed for the other half of the crews. Even though every attempt was made to equate the original version of a mission part with its modified version, there remains the possibility that they were not of equal difficulty. Mission version was also counterbalanced across crews. That is, half of the crews received the original mission parts first and the modified version second. This order was reversed for the other crews. Four crews were required for a complete balanced design, as shown in Table 1.

Table 1: A fully counter-balanced experimental design

IAI Condition	**Scenario Part**		
IAI ON	1	2	3
IAI OFF	1	2	3
	Low	Medium	High
	Level of Temporal Workload		

3.6 Task and procedure

The experiment started with a ten-minute introduction to participants about the general purpose of the experiment. The crews were then given a two-hour training on the use of the workstation interface. During this training session, the crews were given a practice scenario. They were tasked to investigate a single contact using a VTUAV. The crews practiced until they were familiar enough with their workstation functions, and they could identify this contact both quickly and effectively.

After the practice session, the crews were given a twenty-minute briefing by the NAVCOM. NAVCOM's primary role was to act as the liaison between the experimental staff and each crew. The detailed briefing covered various mission aspects including the mission scenario and the number of mini UAVs they had at their disposal. Most importantly, it informed the crews about the key visual features that distinguished the terrorist vessel from other unknown vessels (i.e., hydraulic lifts on the side of a ship container and doors that opened horizontally instead of vertically).

The crews began the first of six experimental sessions after all questions regarding the information covered in this briefing were answered. The first experimental session took about twenty minutes to complete. After this session, each participant was asked to complete the subjective questionnaire. They were asked to rate various aspects of their SA, performance, confidence, and workload.

The crews began the second of six experimental sessions after completion of the first questionnaire. The second session also took about twenty minutes to complete, and then the crews were again given a questionnaire. The first day of testing ended once the questionnaire was completed.

On the second day, the crews completed the remaining four experimental missions and the associated questionnaires. The crews completed two of the sessions in the morning and two in the afternoon. The third and fourth sessions each took about twenty five minutes to complete, and the fifth and sixth sessions required about thirty minutes. The crews were then asked to complete a usability questionnaire regarding the realism of the scenario and the efficacy of the operator-machine interface (e.g., the TACPLOT, the PEP) upon completion of the sixth (and final) session and questionnaire. They were finally debriefed about the critical aspects of the experiment. The crews were also reminded not to divulge any of this information to other military personnel at CFB Comox or CFB Greenwood as it could contaminate the data if future crews knew the purpose of the experiment prior to participating in it.

4 Experimental results

Statistical analyses were performed for eight dependent measures on eight crews with two completed sets of counterbalanced data. All data were subjected to a paired and three paired samples t-test comparing performance across both levels of IAI Condition (ON vs. OFF) and three levels of Operator Workload (Mission Part 1 vs. 2 vs. 3), respectively. These eight measures are:

1. Completion time for various CTS (shorter CTS completion time is better)
2. Percentage of CTS shedding (fewer sequences shed is better)
3. Corrected route trajectory score (values < half nm/min represent a good trajectory with little wasted time)
4. Number of times that the UAVs flew within half nm of a vessel (lower number of times is better)
5. SAGAT score for six experimental sessions (higher score is better)
6. Perceived SA for various tasks (higher score is better)
7. Perceived workload associated with mission tasks (low ratings are better)
8. NAVCOM assessment of crew performance (higher ratings are better)

The results and associated 95% confidence intervals for both levels of IAI Condition and three levels of Operator Workload are shown in Figures 11, 12 and 14 to 19.

Although CTSs were determined a priori for Part 1, they were not included in this analysis as they were of little interest due to the minimal workload associated with this part of the scenario. As such, only CTSs and other measures associated with Parts 2 and 3 will be discussed.

4.1 Critical Task Sequence (CTS) completion time

The CTS data were subjected to a 2 (IAI ON vs. OFF) x 2 (Operator Workload: Medium vs. High) repeated measure of analysis of variance (ANOVA). Although CTSs were identified for Part 1, they were, for the most part, qualitatively different from those identified for Parts 2 and 3. Therefore, it is inappropriate to compare CTS data from Part 1 to Parts 2 and 3. Consequently, only CTS data from Parts 2 and 3 are analyzed here.

There was a significant effect of Workload (Mission Part): where crews were significantly faster at completing CTSs in Mission Part 3 (59.8 sec, $SD = 23.6$) than in Mission Part 2 (97.9 sec, $SD = 35.1$), $F(1, 7) = 9.79$, $MSE = 1198$, $p < .05$. These data are shown in Figure 11.

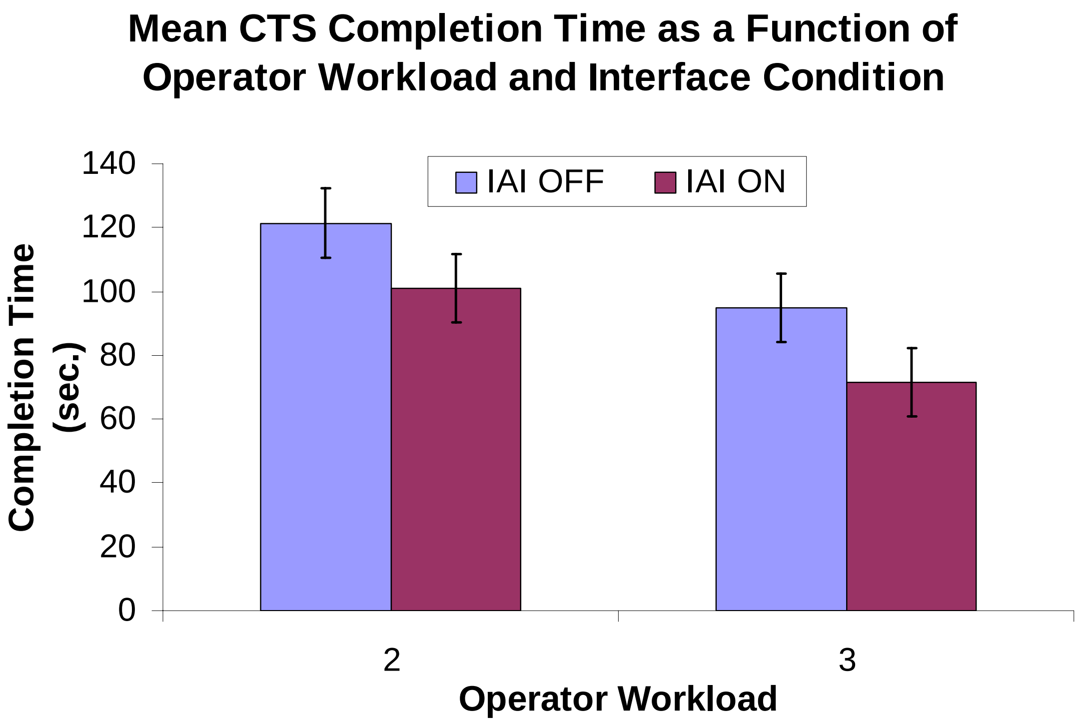

Figure 11: CTS completion time as a function of workload and interface condition

4.2 Percentage of CTS shedding

The CTS task shedding data were subjected to a 2 (IAI ON vs. OFF) x 2 (Operator Workload: Medium vs. High) repeated measure of ANOVA. Data from Part 1 are not included in this analysis for the same reason as stated for the CTS completion time data.

There was a significant effect of Workload (Mission Part): where crews shed significantly more tasks in Mission Part 3 (26.8%, SD = 10.6) than in Mission Part 2 (5.5% sec, SD = 5.4), $F(1, 7) = 64.65$, MSE = 54, $p < .001$. These data are shown in Figure 12.

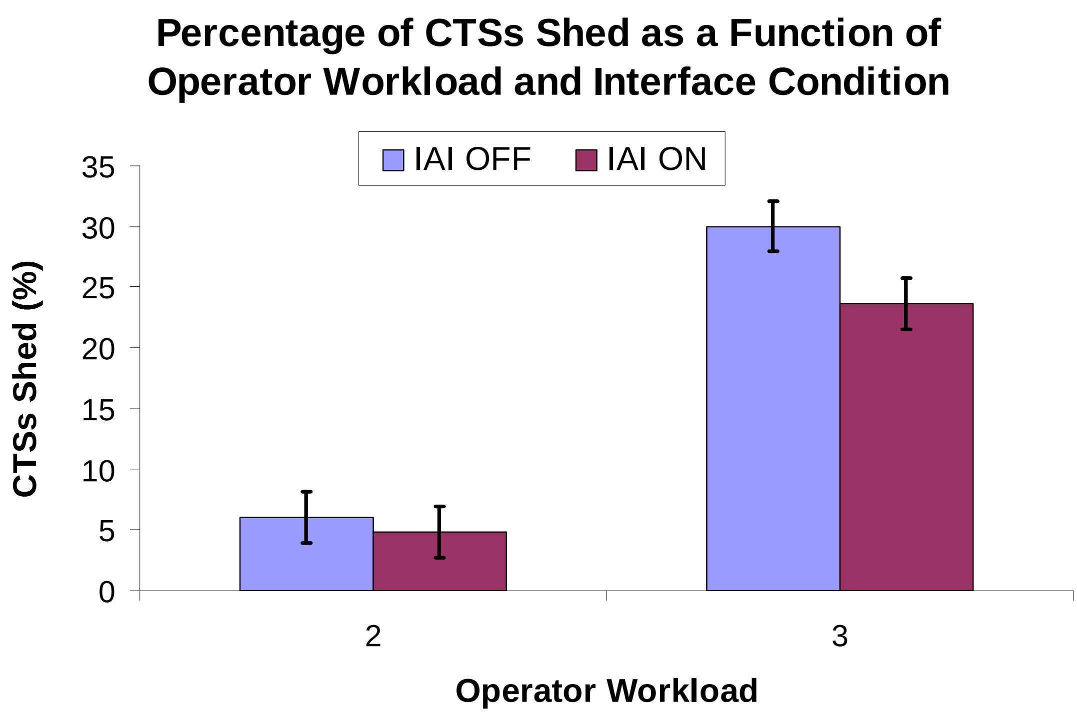

Figure 12: Percentage of CTS Shed as a function of workload and interface condition

4.3 Route Trajectory Score

Figure 13 shows an example of the Route Trajectory Score, which is a sample plot from Crew 7 performance during Part 3 of IAI OFF. The data associated with the mission part are contained in the bottom left of the plot. Each plot data set contains information of the scale of the drawing and the numbers of the UAV and boat being investigated as well as the relevant results for the mission part. These results include:

1. The time that the UAV was flown within the half nm stand-off (no fly) circle from each boat;
2. The mission time at which the UAV first approach to a point within 3 nms of the boat. This was used for subsequent calculations of time to complete critical task sequences; and
3. The trajectory score, which is the average number of nms unused (per minute) because the UAV was not flown at high speed directly towards the closest unknown boat.

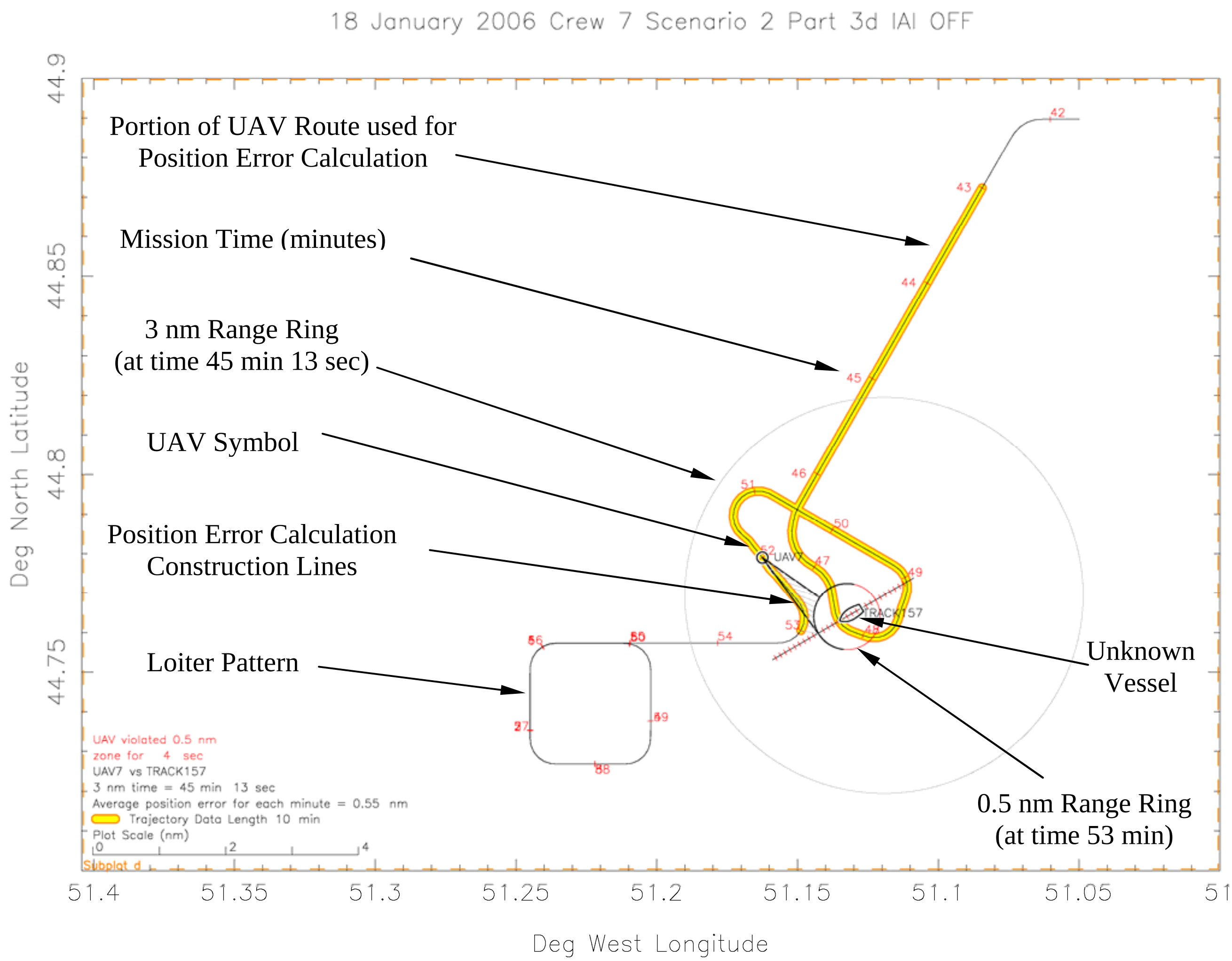

Figure 13: Sample of trajectory plot

The corrected route trajectory score data were subjected to a 3 (Operator Workload: Low vs. Medium vs. High) x 2 (Interface Condition: IAI ON vs. OFF) repeated measure of ANOVA. There was a significant effect of Mission Part, $F(2, 14) = 37.55$, $MSE = .02$, $p < .001$. Three post-hoc paired samples t-test using a Bonferroni correction to guard against alpha slippage (i.e., dividing the set alpha level (.05) by the number of post hoc comparisons (3) to obtain a new alpha level (0.016)) showed that the crews' route trajectory was significantly better in Mission Part 1 (0.26, $SD = 0.18$) than in Mission Part 2 (0.43, $SD = 0.16$) or in Mission Part 3 (0.68, $SD = 0.09$), $t(7) = 4.67$, $p < .005$, $t(7) = 6.78$, $p < .001$, respectively. Further, the crews' route trajectory was significantly better in Mission Part 2 than in Mission Part 3, $t(7) = 5.67$, $p < .001$.

The main effect of Interface Condition was also significant, $F(1, 7) = 21.77$, $MSE = .02$, $p < .005$, with the crews' route trajectory being significantly better with IAI ON (0.36, $SD = 0.15$)

than with IAI OFF (0.55, SD = 0.12). The interaction between Mission Part and Interface Condition was also significant F (2, 14) = 11.71, MSE = .02, p < .005. As predicted, this interaction took the form in which the benefits of the IAI increased as operator workload (scenario complexity) increased. These data are shown in Figure 14.

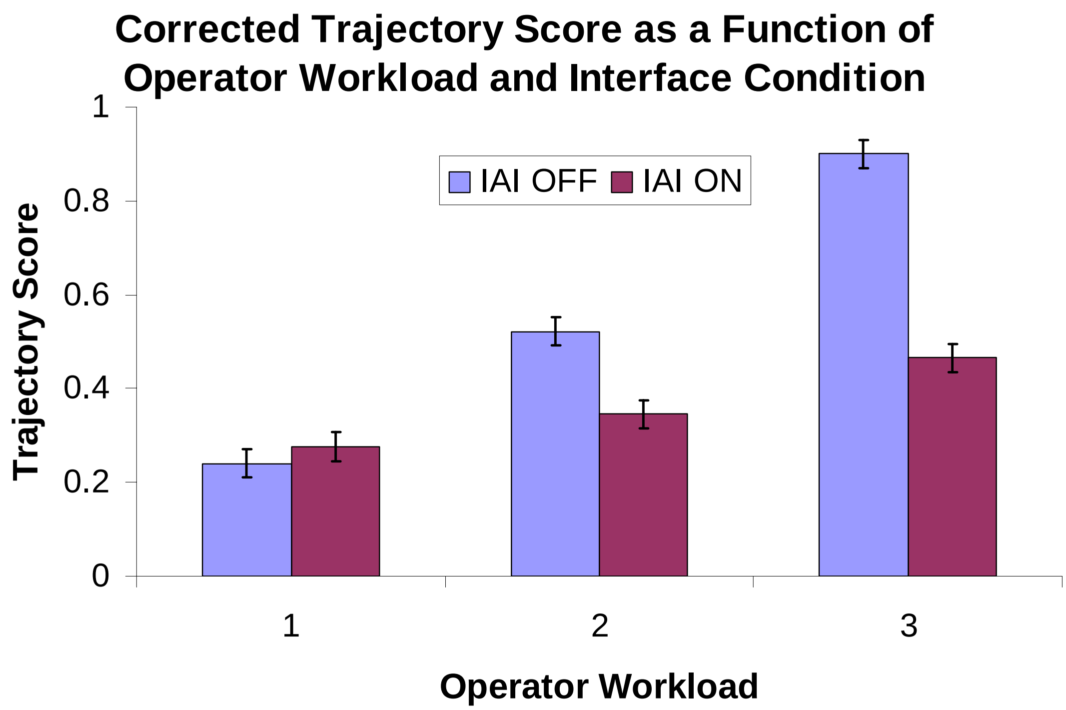

Figure 14: Trajectory score as a function of workload and interface condition

4.4 Airspace violation

The number of times each crew violated the ½ nm radius surrounding each contact with one of the critical UAVs was summed to provide a cumulative score. The restriction was that a UAV could only violate the airspace surrounding any given contact once for each mission part. As described above, there were fourteen critical UAV-contact parings for each crew. Thus, the maximum number of airspace violations for any given crew is fourteen. These airspace violation data were subjected to a 3 (Operator Workload: Low vs. Medium vs. High) x 2 (Interface Condition: IAI ON vs. OFF) repeated measure of ANOVA. There was a significant effect of Mission Part, F (2, 14) = 10.63, MSE = .38, p < .005. Three post-hoc paired samples t-test (using a Bonferroni correction) showed that the crews had a significantly fewer number of airspace violations in Mission Part 1 (2 violations) than in Mission Part 3 (18 violations), t(7) = 4.00, p < .005.

The effect of Interface Condition was also significant, F (1, 7) = 6.82, MSE = .69, p < .05, with the crews having significantly fewer airspace violations when IAI was on (8 violations) than when it was off (23 violations). The interaction between Mission Part and Interface Condition was also significant F (2, 14) = 6.66, MSE = .37, p < .01. As predicted, this interaction took the form in which the benefits of the IAI increased as operator workload (scenario complexity) increased. These data are shown in Figure 15.

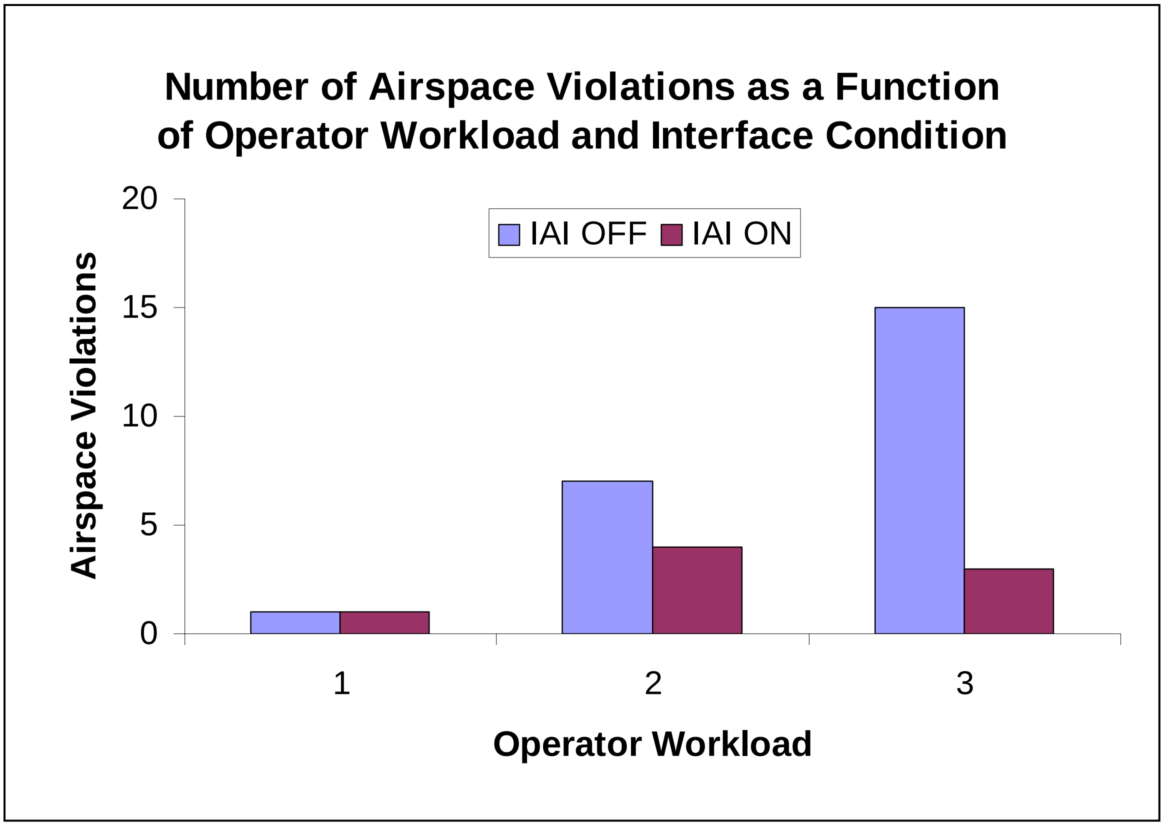

Figure 15: Number of airspace violations as a function of workload and interface condition

4.5 Situation Awareness Global Assessment Technique (SAGAT) score

The SAGAT data were subjected to a 3 (Operator Workload: Low vs. Medium vs. High) x 2 (Interface Condition: IAI ON vs. IAI OFF) repeated measure of ANOVA. The effect of Interface Condition was significant, t(7) = 4.17, p < .005, with crews having significantly lower SA (higher SAGAT scores) when IAI was OFF (5.60, SD = 0.69) than when it was ON (4.82, SD = 0.45). These data are shown in Figure 16.

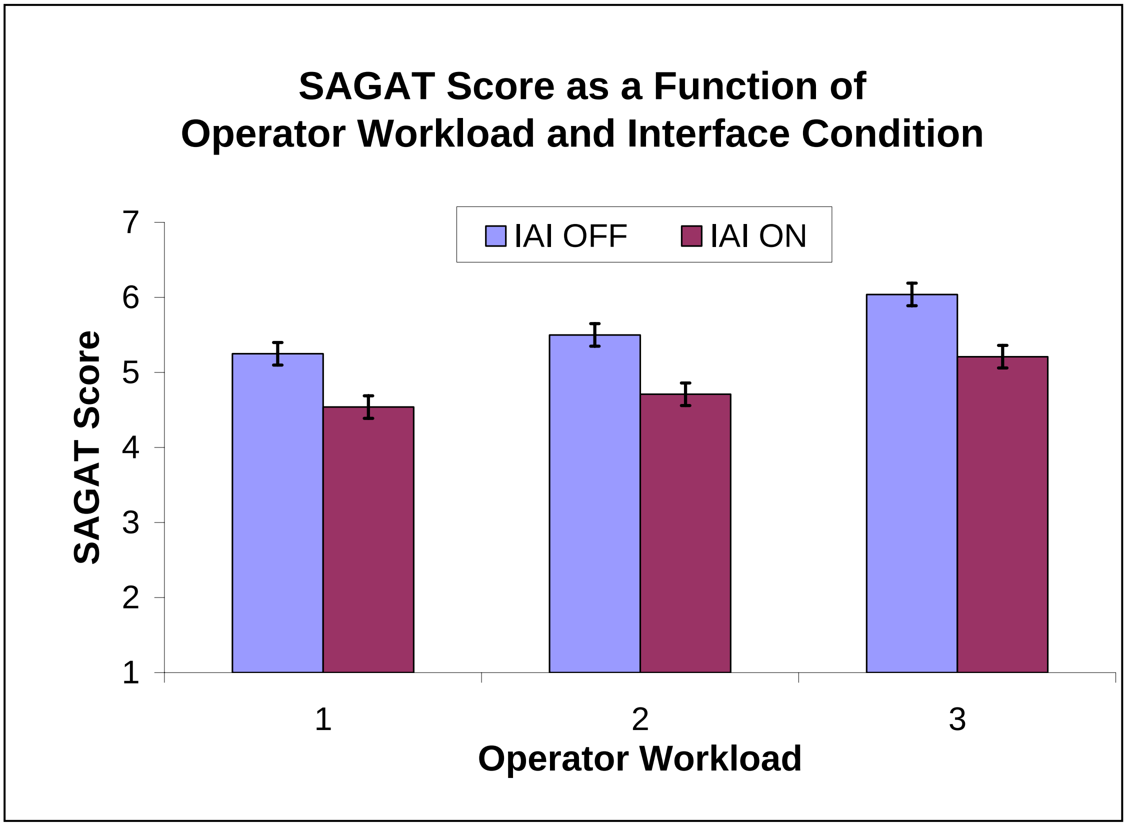

Figure 16: SAGAT score as a function of workload and interface condition

4.6 Perceived Situation Awareness (SA)

The perceived SA data were subjected to a 3 (Operator Workload: Low vs. Medium vs. High) x 2 (Interface Condition: IAI ON vs. IAI OFF) repeated measure of ANOVA. There was a significant effect of Mission Part, $F(2, 14) = 14.98$, $MSE = .10$, $p < .001$. Three post-hoc Wilcoxon matched pairs signed-ranks tests (using the Bonferroni correction) showed that the crews' perceived SA was significantly higher in Mission Part 1 (5.67, $SD = 0.37$) than in Mission Part 2 (5.38, $SD = 0.45$) or than in Mission Part 3 (5.04, $SD = 0.48$), $T(8) = 1$, $p < .02$, $T(8) = 0$, $p < .01$, respectively.

The effect of Interface Condition was also significant, $F(1, 7) = 5.97$, $MSE = .13$, $p < .05$, with the crews' perceived SA being significantly better with IAI ON (5.49, $SD = 0.37$) than with IAI OFF (5.24, $SD = 0.59$). These data are shown in Figure 17.

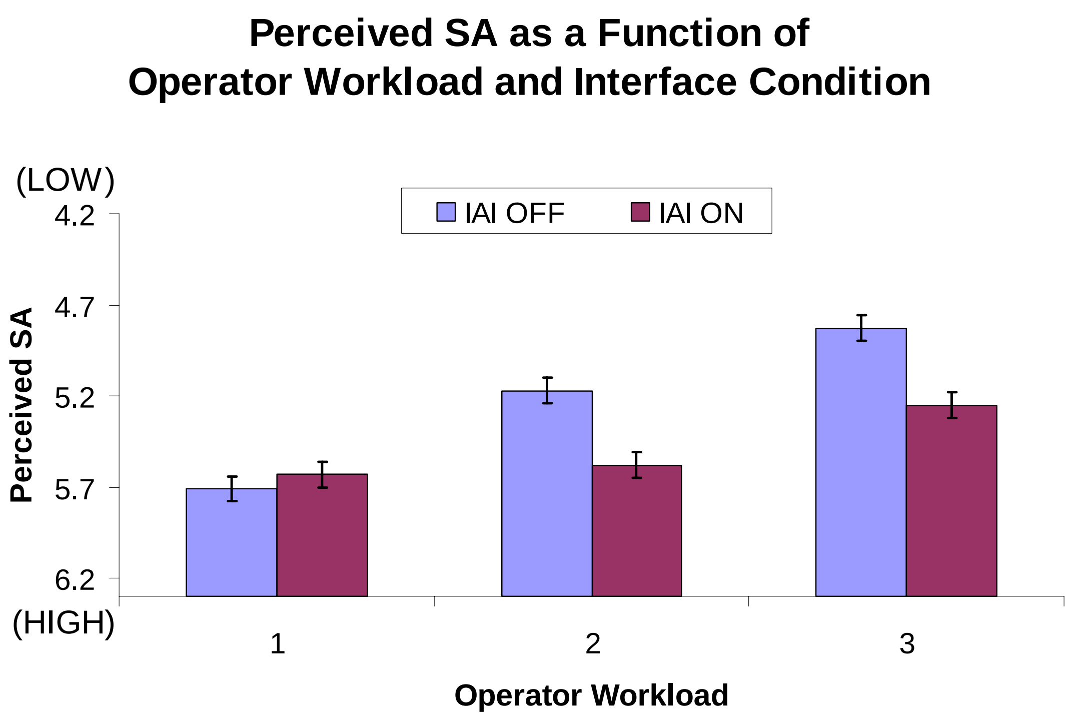

Figure 17: Perceived SA as a function of workload and interface condition

4.7 Perceived workload

The perceived workload data were subjected to a 3 (Operator Workload: Low vs. Medium vs. High) x 2 (Interface Condition: IAI ON vs. OFF) repeated measure of ANOVA. There was a significant main effect of Mission Part, $F (2, 14) = 30.31$, $MSE = 87$, $p < .001$. Three post-hoc Wilcoxon matched pairs signed-ranks tests (using the Bonferroni correction) showed that the crews' perceived workload was significantly lower in Mission Part 1 (25.04, SD = 9.26) than in Mission Part 3 (50.40, SD = 4.78), $T(8) = 0$, $p < .01$. The crews' perceived workload was also significantly lower in Mission Part 2 (34.37, SD = 4.90) than in Mission Part 3, $T(8) = 0$, $p < .01$.

The effect of Interface Condition was also significant, $F (1, 7) = 12.08$, $MSE = 87$, $p < .01$, with the crews' perceived workload being significantly lower with IAI ON (31.94, SD = 14.91) than with IAI OFF (41.28, SD = 12.91). The interaction between Mission Part and Interface Condition was significant as well, $F (2, 14) = 4.31$, $MSE = 42$, $p < .05$. As predicted, this interaction took the form in which the benefits of the IAI generally increased as operator workload (scenario complexity) increased. These data are shown in Figure 18.

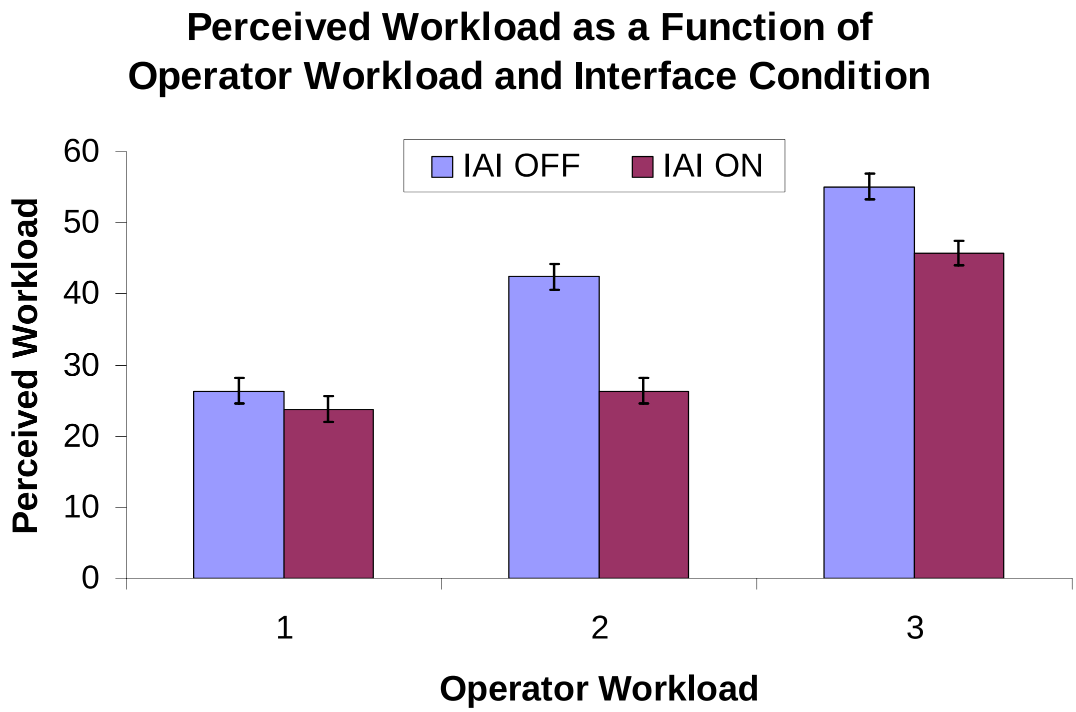

Figure 18: Perceived workload as a function of workload and interface condition

4.8 NAVCOM's assessment of crew performance

The NAVCOM provided a rating for each participant after each of the six mission parts. The assessment data were subjected to a 2 (IAI Condition: ON vs. OFF) x 3 (Operator Workload: Low vs. Medium vs. High) repeated measure of ANOVA. The NAVCOM reported that the crew performed significantly better when IAI was ON (6.08 combined score) than when it was OFF (5.42 combined score), $t(7) = 3.31$, $p < 0.05$.

The IAI Condition by Operator Workload interaction was also significant, $F = 6.85$, $p < 0.01$. As can be seen in Figure 19, this interaction is produced by the IAI functionality significantly improving performance (as rated by the NAVCOM) for mission parts 2 and 3, but not for mission part 1.

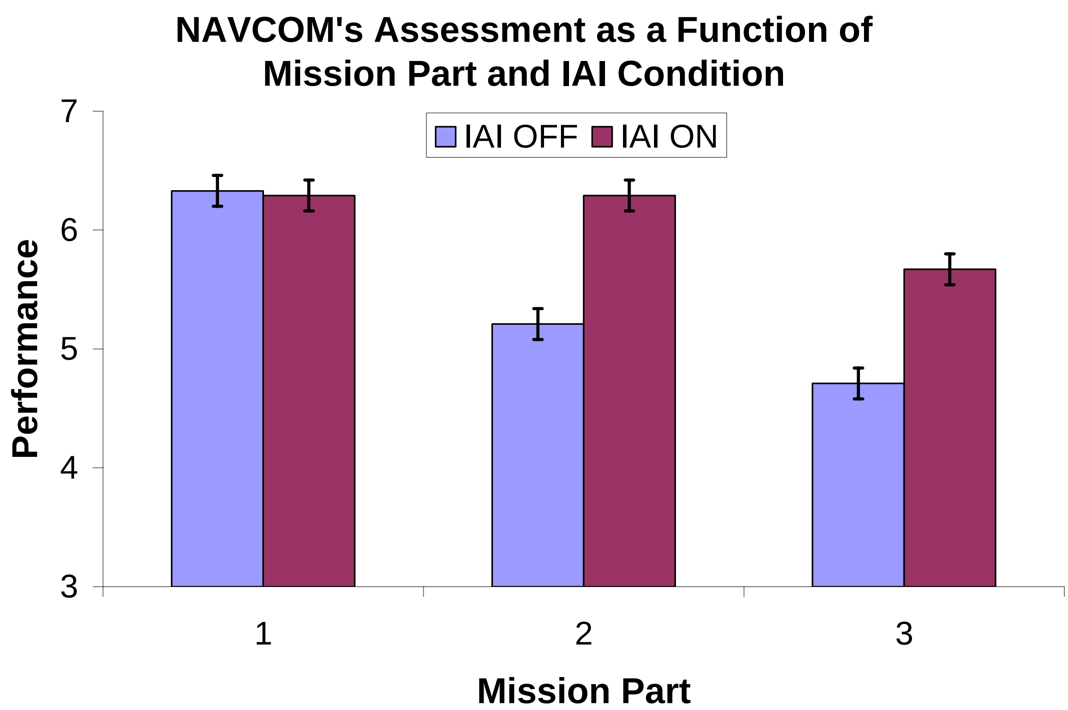

Figure 19: NAVCOM's assessment of crew performance as a function of workload and IAI condition

4.9 Findings

The experimental results revealed that participants could manage tasks faster in Part 3 (see Figure 11) although the workload was higher in this part than any other part. This is because IAI might help participants manage some tasks or perhaps some tasks were shed (by participants) as there were too many to handle in Part 3. However, there were fewer CTSs shed when IAI was ON than OFF (see Figure 12) in Part 3, which means IAI helped participants manage some tasks. In addition, subjective results revealed that overall SA was improved when IAI was ON although participants had the highest workload in Part 3 (see Figures 17 and 18). The results were supported by the SAGAT scores, which showed a significant improvement in SA when IAI was ON (see Figure 16). Thus, IAI likely helped participants to work faster with improved SA.

Further, the results of both objective measures (CTS Completion Time, Percentage of CTS Shedding, UAV Route Trajectory Score, and UAV Airspace Violation Time) and Workload subjective measure (see Figures 11, 12, 14, 15, 17, and 18) indicate that performance was improved and overall workload was significantly reduced when IAI was ON in both Parts 2 and 3. Figures 16 and 17 depicted that SA was also improved when IAI was ON in both Parts 2 and 3. When IAI helped out and/or more tasks were shed, participants could maintain better SA even though they had the highest workload in Part 3. Thus, it is likely that they could manage mission tasks in a faster pace with better trajectory scores and less airspace violation time (see Figures 11, 12, 14, and 15) with IAI ON. Therefore, the claim of IAI's positive impact on reducing workload and enhancing situation awareness as well as performance were supported.

In general, the results indicated that participants performed more effectively from both quantitative and qualitative perspectives when the IAI was ON. When IAI was ON, CTSs were shortened, fewer tasks were shed, the UAV trajectory scores were better and the no-fly areas were violated less often (see Figures 11, 12, 14, and 15). Participants' overall (actual and perceived) SA was improved and overall workload was reduced as well (see Figures 16, 17, and 18). Note that many of the CTSs examined in the experiment were previously modeled and simulated in the first phase of this research. They were the sequences performed by the very same IAI agent groups (e.g., route planning and inter-crew communication) used in both the simulation and experimentation phases. Thus, consistent test results (e.g., reduced task completion time and operator workload) of these CTSs in the experimentation phase validated the network modeling results concluded in the simulation phase. Participants' performance was improved through the use of an IAI although they were working in a cognitively complex situation.

5 General discussion

The IAI implemented as a prototype here is only a small subset of a more extensive suite of fully optimized UAV agent system. However, the experimental findings indicated that the control of a dynamic and complex system such as multiple disparate UAV control from an airborne platform can be improved through the use of a multi-agent IAI suite. Experience and knowledge were gained regarding the design of IAI agents, the implementation of synthetic IAI prototype environments, and the conduct of the experiments through the discussions and observations made during the conduct of the project. Hubbard, et al. (2006) hypothesized that as the level of complexity increases within these scenarios, the degree to which software agents outperform humans increases.

5.1 Technical account of IAI prototype

First, the experimental set-up was a well designed and developed environment for exploring the provision of assistance to operators. It has been excellent for determining how to produce an IAI. As the project continued, the list of potential IAI functions grew when more knowledge about IAI systems was gained. The actual number of agents developed in the experiment was limited. The quality of the implementation was good though not at the quality of a production system. Even so, the results found were very supportive of the use of IAI agents in the complex environment. A more complete set of agents would result in increased crew performance.

Second, the most effective IAI agents in the prototype interfaces were: route planning, route following, and inter-crew communication support agents. These three IAI components were the same agents identified by the HGA conducted in the first phase of the project.

Third, some aspects of the experiment limited the perceived effectiveness of the IAI. The conventional user interface was already well designed to be effective according to human factors engineering principles. Participants were trained on the conventional interface for which they had developed work strategies, not on the IAI. They might rely on the original work strategies because they were known and effective when the IAI functionality was selected as ON. In addition, the participants came in for only two days. The novelty of the conventional interface would not have worn off after the training sessions. Participants would rather work with the interface manually than give up control to the IAI. These factors might have limited effectiveness of IAI use though the experimental results revealed performance improvements.

5.2 IAI design recommendations

The other purpose of this study is to develop guidelines for IAI design. Special attention was paid to this aspect during all project phases and a subset of the knowledge gained is outlined here.

5.2.1 IAI issues

First, feedback presentations are a high priority for interface design when IAI agents are employed. This was demonstrated during the GUI design effort. For example, when the requirement for HGA feedback (upwards flow of information within the hierarchy of goals) was indicated as an important display item, the IAI specific communication message window was decided to be one of the IAI features in interfaces, as introduced in Section 2.2.

It is important that an operator interface allows operators to return to the state in effect before the IAI reconfigures the display parameters. In other words, a "Return to Previous State" (BACK) button and a "Default Settings" button should be added to the IAI display. IAIs must be designed to ensure that they are not perceived to take over control. It is critical that the system informs the user of changes on the interface. The IAI should either indicate for a few seconds where it is going, or indicate what has been changed.

The design of each IAI agent in a prototype interface must be based on available information in real operations. The interface designer must be realistic with regards to the information available on a system data inventory. In a modelling and simulation environment, the design engineers know the ground truth. However, some information used in simulation cannot be obtained from a real live subsystem. In other words, during the design and development of an IAI, every attempt should be made to ensure that an IAI agent "is aware" of the state of the world. This may include access to data fusion interim variables and associated probabilities, which would allow the IAI to produce strategies that "play the odds".

There is a qualitative difference that an IAI interface requires an operator to manage his or her UAVs. Using a conventional interface the operator provides heading and altitudes. When an IAI is used, the operator provides goals or mission objectives. The IAI must be designed to not misinterpret intentions, for example, initiating a holding pattern when a pilot is trying to fly to a distant refuelling location. The operator moves beyond inserting parameters but rather insert or establish system objectives. The design and development team should evaluate the operator's activities and try to move his/her thinking from the operating level to the strategic level.

All IAI functions should be studied during design and development and incorporated into a user evaluation. A thorough investigation also should be conducted to confirm that the concept is implemented adequately for the assessment. Poor implementation will not increase the value of any IAI function but mask the true acceptance or potential improvement in effectiveness.

5.2.2 Potential IAI roles

There were only six sets of IAI agents (functional groups) implemented in the prototype interfaces. There are other sets of IAI candidates which are good at assisting operators in effective decision-making, especially in the context of multiple UAV control.

First, an IAI agent would be able to generate suggestions. For example, when a UAV is flying away for the perceived scene of action, the agent may query an operator with a question similar to: "Do you want me to turn UAV 3 around?" The agent would have to recognize that a UAV was being ignored or had been forgotten.

Second, an IAI agent may build on other existing software to help complete part of the background data analysis. For example, the data fusion calculations based on different routes of different UAVs could lead to optimal route selection to maximize fused data. This information would be used by an IAI route planning agent.

Third, an IAI agent may intelligently provide information to the crew by sequentially selecting the most relevant data items for display. This could be similar to the CNN news, which continuously moves from a news story to another news story with the sequence depending on the latest breaking information and the relevance to the viewers. In this way, a UAV operator could adjust to the most recent video from the team of UAVs investigating contacts. This may lead to a "ticker tape" of information scrolling across the display.

Fourth, an IAI agent may produce a "heading" path for every UAV to indicate (to an operator) where each UAV will be flying. The "heading" path would be reassessed and modified as required. If a contact were to "pop-up", the agent would plan routes to accommodate the unknown. The agent could produce a plan and offer it up for acceptance, or it could implement the new plan and modify the UAV paths shown on the TACPLOT. Each optimal flight path may have holding patterns identified. A design challenge would be the level of autonomy allocated to the group of UAVs and identification of the appropriate holding points at which operators' overview would, should, or must occur.

Fifth, an IAI agent may be self-preservative. This IAI function would maintain altitude separation between UAVs and would warn a pilot if a UAV was descending into the water. Additionally, the agent would ensure that the engine was operating and a minimal floor height maintained (with a standard holding pattern if necessary) to keep the UAV from crashing.

Sixth, another IAI agent may assess the utility of all of the UAVs. Each UAV would be assessed for utility and possible redeployment. This would identify UAVs that were flying away from the area of interest. This is a case where the agent could suggest a new route (or a holding pattern) and ask an operator if he or she would like to have the new route implemented. The agent could also advice the operator to automatically redirect the UAV to prosecute an unknown contact. Similarly, the agent could be controlled to prosecute multiple targets efficiently. The agent could implement a minimum cost function to use the available resources to investigate all contacts as quickly as possible.

Finally, each IAI agent may have a different level of autonomy appropriate to the function. An example of various levels of autonomy would be a pilot accepting full route planning and route following while a sensor operator uses an IAI "advise" mode rather than full turret repositioning.

6 Conclusions

This research assessed the efficacy of IAI technology in a dynamic and complex military system, and further provided generic design guidance on IAI systems. A task network model was developed based on a HGA for an operational scenario which involved controlling multiple UAVs from an airborne platform. Three IAI functional agent groups were simulated in a performance modeling environment to predict operators' performance. The same three agents and other three IAI function groups were implemented in a synthetic prototype system for an empirical evaluation. The experimental results confirmed the findings of performance modeling and further supported the hypotheses about using IAIs to reduce workload and improve SA and performance. Although IAIs were operated in either ON or OFF mode in the prototype interfaces, the research findings showed potential optimal conditions to trigger IAIs under different cognitive workload situations.

This study is a typical example of designing an IAI as an augmented cognition aid to address complexity, dynamics, and information overflow issues associated with many military systems used in network centric warfare or any other networked systems. The benefits of using IAIs in these systems for the intelligent adaptive assisting of the decision-making processes have been demonstrated. Knowledge obtained from the processes of concept development, performance modeling, prototype implementation, and experimentation has helped to generate preliminary guidelines for designing IAI systems.

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Annex A Experimental protocol

Original DRDC Toronto Protocol #L-511

Title: Experimental Assessment of Intelligent Adaptive Interfaces for UAV Operators
Principle Investigator: Dr. Ming Hou, DRDC Toronto (Thrust 13il)
Run Director: Mr. Bob Kobierski, CMC Electronics Inc. (Ottawa)

A.1 Executive Summary

A.1.1 Background

The Canadian Forces (CF) is considering more widespread use of Uninhabited Air Vehicles (UAVs) to provide a new integrated intelligence, surveillance, and reconnaissance (IISR) capability. In this role, UAVs would be force multipliers, releasing manned aircraft for other roles. However, at the moment UAV control is operator intensive and can involve high levels of workload. Intelligent Adaptive Interfaces (IAIs) are a potential technology for controlling operator workload and improving decision effectiveness in the employment and operation of these platforms. Defence Research & Development Canada (DRDC) has initiated a project for the definition and development of IAIs for advanced UAV control under Thrust 13i for the Air Environment. The aim of this project is to develop, demonstrate, and prioritize enabling technologies that can be applied to an advanced operator interface that will support reduced manning and enhanced performance in complex military systems, specifically UAV control from an airborne platform. The overall project involves three phases and lasts three years. In the first two phases, theoretical frameworks and design concepts have been developed, and followed by prototype interface design and implementation. The work being conducted in the last phase here is to conduct experimental evaluation on these IAI interfaces in CMC Electronics Inc who is under contract with DND to perform this work.

A.1.2 Purpose

The purpose of this research is to conduct an experimental evaluation of the efficacy of prototype IAIs in a simulated environment for the control of multiple UAVs from an airborne platform.

A.1.3 Procedure

Participants will be tested as a team of three-aircrew individuals in a simulated UAV control compartment on CP140 Aurora. The participants will be required to sit in front of the simulated UAV control stations and work with their own operator interfaces in which a counter-terrorist scenario will be presented. The participants' task will be to control multiple UAVs and to search and locate a terrorist boat. The entire experiment will take about fifteen (15) hours including briefing, training, two separate one-hour trials and one-hour debriefing session.

A.1.4 Benefit

The results from this study will increase the understanding of the impact of automated systems on the enhancement of CP140 capability, especially the integration with multiple UAV control systems on board.

A.1.5 Risks

No unusual risks are. Although there are no anticipated risks, the participants will be informed that they have the right to terminate the trial at anytime. The participants will not be subjected to medical screening. The participants will not receive undue physical and/or mental stress due to participation within the study. No physician coverage is required for the study.

A.2 Glossary Of Terms and Acronyms

ALIX	Atlantic Littoral Intelligence, Surveillance, and Reconnaissance Experiment
AOO	Area of Operations
AS	Adaptive Systems
ASO	Acoustic Sensor Operator
CC-130	Hercules
CC-144	Challenger
CCG	Canadian Coast Guard
CF	Canadian Forces
CFEC	Canadian Forces Experimentation Centre
CMC	CMC Electronics Inc.
CP140	Aurora
CPF	Canadian Patrol Frigate
CTS	Critical Task Sequence
DFO	Department of Fisheries and Oceans
DRDC	Defence Research & Development Canada
FY	Fiscal Year
GUI	Graphical User Interface
HGA	Hierarchical Goal Analysis
IAI	Intelligent Adaptive Interface
IISR	Integrated Intelligence, Surveillance, and Reconnaissance
IUI	Intelligent User Interface
MALE	Medium Altitude Long Endurance
NavCom	Navigator Communicator
NASO	Non-Acoustic Sensor Operator
OGD	Other Government Department
OTH	Over The Horizon
PCT	Perceptual Control Theory.
PDT	Perceptual Detection Task
PEP	Programmable Entry Panel
PLIX	Pacific Littoral Intelligence, Surveillance and Reconnaissance Experiment
R&D	Research and Development
SAGAT	Situation Awareness Global Assessment Technique

SME	Subject Matter Expert
TN	Tactical Navigator
UAV	Uninhabited Aerial Vehicle
UCAV	Uninhabited Combat Aerial Vehicle
UO	UAV Sensor Operator
UP	UAV Pilot
VTUAV	Vertical Take-Off UAV

A.3 Ethics Committee Protocol

A.3.1 Protocol Number

The protocol number for the present study is: L-511.

A.3.2 Title

Experimental Assessment of Intelligent Adaptive Interfaces for UAV Operators.

A.3.3 Investigator

Principal Investigator: Dr. Ming Hou, DRDC Toronto

A.3.4 Background

The Canadian Forces (CF) is considering more widespread use of Uninhabited Air Vehicles (UAVs) to provide a new Integrated Intelligence, Surveillance, and Reconnaissance (IISR) capability. In this role, UAVs would be force multipliers, releasing manned aircraft for other roles. However , at the moment UAV control is operator intensive and can involve high levels of workload. Intelligent Adaptive Interfaces are a potential technology for controlling operator workload and improving decision effectiveness in the employment and operation of these platforms.

Defence Research & Development Canada (DRDC) has initiated a project for the definition and development of IAIs for advanced UAV control under Thrust 13i for the Air Environment. The aim of this project is to develop, demonstrate, and prioritize enabling technologies that can be applied to an advanced operator interface that will support reduced manning and enhanced performance in complex military systems, specifically UAV control from an airborne platform.

The overall project involves the following three phases and will last 3 years:

Year 1 Concept development and theoretical frameworks. Year 1 work is now complete.

Year 2 Prototype Interface design and implementation; including the creation of the simulation environment and performance measurement suite for experimental evaluation. Year 2 goals are now achieved.

Year 3 Demonstration of the concept and experimental evaluation including the production of draft design guidelines for IAIs and the generation of a follow-on Technology Demonstration proposal. This phase provides the scope for the current work.

The domain of application for the demonstration of IAI capability is advanced UAV control, focusing on those technologies that increase the ratio of UAV to operator. An operational mission scenario has been devised, and hierarchical goal analyses/performance modelling was conducted in Year 1 of the project.

Year 2 of the Project included the development of interface design concepts, the implementation of prototype interfaces for the creation of simulation environments, and preparation of a performance measurement suite for the future experimental evaluation. The work of this phase also resulted in an experimental environment including the control of interface intelligence, temporal workload, and task complexity for three UAV operators in order to run the experiment.

The work described hereby is for Year 3 of the Project and includes the modification of both conventional and “Wizard-of-Oz” prototype interfaces for experimentation purpose. The use of actual IAI agent software within the interface will also be demonstrated. The experimental data will be collected and analyzed statistically to testify the efficacy of IAI technology. The experimental results will result in a preliminary guideline for designing IAIs according to the recommendations based on the comparison of UAV operator interfaces with and without IAI components.

A.3.5 Purpose of Study

The objective of this experiment is to conduct an experimental evaluation of the efficacy of prototype intelligent adaptive interfaces (IAIs) for the control of multiple UAVs from an airborne platform. Based on the results, recommendations and guidelines will be proposed for the design of IAIs.

A.3.6 Selection of Human Subjects

There will be 8 teams of 3 aircrew individuals with age range from 16 to 60 recruited as volunteers from CP140 community at CFB Greenwood and Comox through 1 Canadian Air Division for the study. These 27 subjects will have no prior UAV controlling history but CP140 operational exposure. Each team will consist of: 1 UAV pilot (UP), 1 UAV sensor operator (UO), and 1 Tactical Navigator (TN). Preferably, the UAV pilot will have some level of experience of piloting CP140, providing that he or she has completed the Operational Training Unit. Similarly, the UAV operator may be junior Non-Acoustic Sensor Operator (NASO), although at least one-year experience would be highly desirable. A qualified TN is also highly desirable, although an "A" category Navigational Communicator (NAVCOM) would also be satisfactory. Since all subjects are well-trained aircrews and tasked to participate in the experiment, they will not be compensated with any stress allowance. All subjects will be fully briefed as to the purpose, details, discomforts, and risks associated with the experimental protocol before being asked for their written informed consent. All subjects will be required to sign the consent form (see attached copy) before participating in the study to indicate that they have been briefed to their satisfaction and have understood the risks.

A.3.7 Methodology

Based on prior hierarchical goal analysis and performance modelling for UAV control activities, the hypotheses were generated for the experimental evaluation. They are:

- the IAI(s) will enhance the Situation Awareness and performance of UAV operators while potentially decreasing workload.
- the impact of IAI(s) will vary across the three UAV operator roles (i.e., TN, UO, UP) and presumably be greatest for the most complex activity.
- the IAI(s) will have the greatest positive impact in high workload situations.

Experimental Design

In order to test the hypotheses above, the impact of the prototype IAIs will be examined using two independent (manipulated) variables: operator workload and interface condition. Hence, the experiment has a 3 x 2 mixed factors design that includes two within-subject variables (Operator Workload: 3 levels that correspond to 3 mission parts), and (Interface Condition: 2 levels that correspond to IAI on versus IAI off). There will be 8 crews of 3 team members (totally 24 participants) recruited for the experiment.

Operator Workload

The missions for this experiment have been designed to incorporate 3 levels of workload that correspond to the 3 mission parts: Par 1 Part 2, and Part 3. The fist part requires the crew to use one UAV to investigate one contact and monitor the balance of the CP140 crew (pilots and NASOs) investigate a second contact. During the second part of the mission, the subject crew will be required to employ two UAVs simultaneously, each investigating a different contact. During the third and highest workload portion of the mission the subject crew will be required to employ up to 5 UAVs at once while prosecuting a terrorist vessel.

Interface Condition

UAV operator interfaces are computer displays on UAV control stations. An operator interface is the only media that operators can interact with the system to control the UAVs remotely. In this study, the interfaces are graphic user interfaces which have been integrated with simulated UAV control stations for the purpose of evaluation on IAI technology.

There are two levels of interface condition correspond to whether an IAI is on (IAI ON) or off (IAI OFF). (Interface condition is not shown in Table 1). When IAI is on, there will be automation features of the interface assisting operators to control multiple UAVs. When IAI is off, operators will have to manually manipulate with the interface to control UAVs.

Two approximately 60-minute missions are required for this experiment. These missions are designed to be similar, but different enough to counter possible familiarity effects. Two different missions are required because each crew is required to undertake the role-playing exercise with and without the IAI selected ON. For example, if the first subject crew is required to accomplish the counter-terrorist mission with the IAI selected OFF (using the conventional interface only); then, when they are testing the system with IAI selected ON, this crew must be presented with a scenario with the unknown boats and the terrorist boat positioned in different locations. If not the crew will demonstrate increased performance, not because the interface is better, but because they know the ground truth. In order to avoid an effect caused by the order in which the two missions are undertaken, the experiment needs to be balanced by requiring Mission 1 to be "flown" first with one crew and Mission 2 to be "flown" first with the next crew.

Each 60-minute mission is divided into 3 parts, referred to as Parts 1, 2, and 3. Thus, there are combinations of Mission (1 or 2) and Parts (1, 2, and 3). Accordingly, M1-P1 refers to Part 1 of Mission 1. M2-P1 refers to Part 1 of Mission 2, etc. Parts are always run in "1-2-3" order. However, for each crew, a part is repeated. For example, the order for Crew 1 will be M1-P1 (with IAI OFF), M2-P1 (with IAI ON). This will allow for a direct comparison of the IAI OFF vs. IAI ON condition for the type of tasks performed in the early (e.g., Part 1) components of the missions.

Each crew will complete 2 full missions, each with 3 parts. For counterbalancing purposes, multiples of 4 crews will be required. That is, either 4 crews, 8 crews or 12 crews. As indicated earlier, the order in which the mission and "flown" must be balanced, but also the order in which the IAI is selected to OFF or ON must also be balanced. As a result, the experiment will require one crew to first fly with IAI OFF on Mission One which will be balanced with a second crew who fist fly with IAI ON on Mission One. These two crews will be balance with two follow-up crews who fly Mission Two first. This is shown in Table A-1.

Table A-1: ***Experimental Design: 2 (Mission) x 2 (IAI Mode)***

IAI Condition	**Crew 1**		
IAI OFF	1. M1-P1	3. M1-P2	5. M1-P3
IAI ON	2. M2-P1	4. M2-P2	6. M2-P3
IAI Condition	**Crew 2**		
IAI ON	1. M1-P1	3. M1-P2	5. M1-P3
IAI OFF	2. M2-P1	4. M2-P2	6. M2-P3
IAI Condition	**Crew 3**		
IAI OFF	1. M2-P1	3. M2-P2	5. M2-P3
IAI ON	2. M1-P1	4. M1-P2	6. M1-P3
IAI Condition	**Crew 4**		
IAI ON	1. M2-P1	3. M2-P2	5. M2-P3
IAI OFF	2. M1-P1	4. M1-P2	6. M1-P3

A.3.8 Experimental Environment

The physical layout of the experimental environment is sketched in Figure A-1. Each of the UAV crew member has his own control station and interface. Figure A-1 shows the images of the physical layout of these workstations and interfaces.

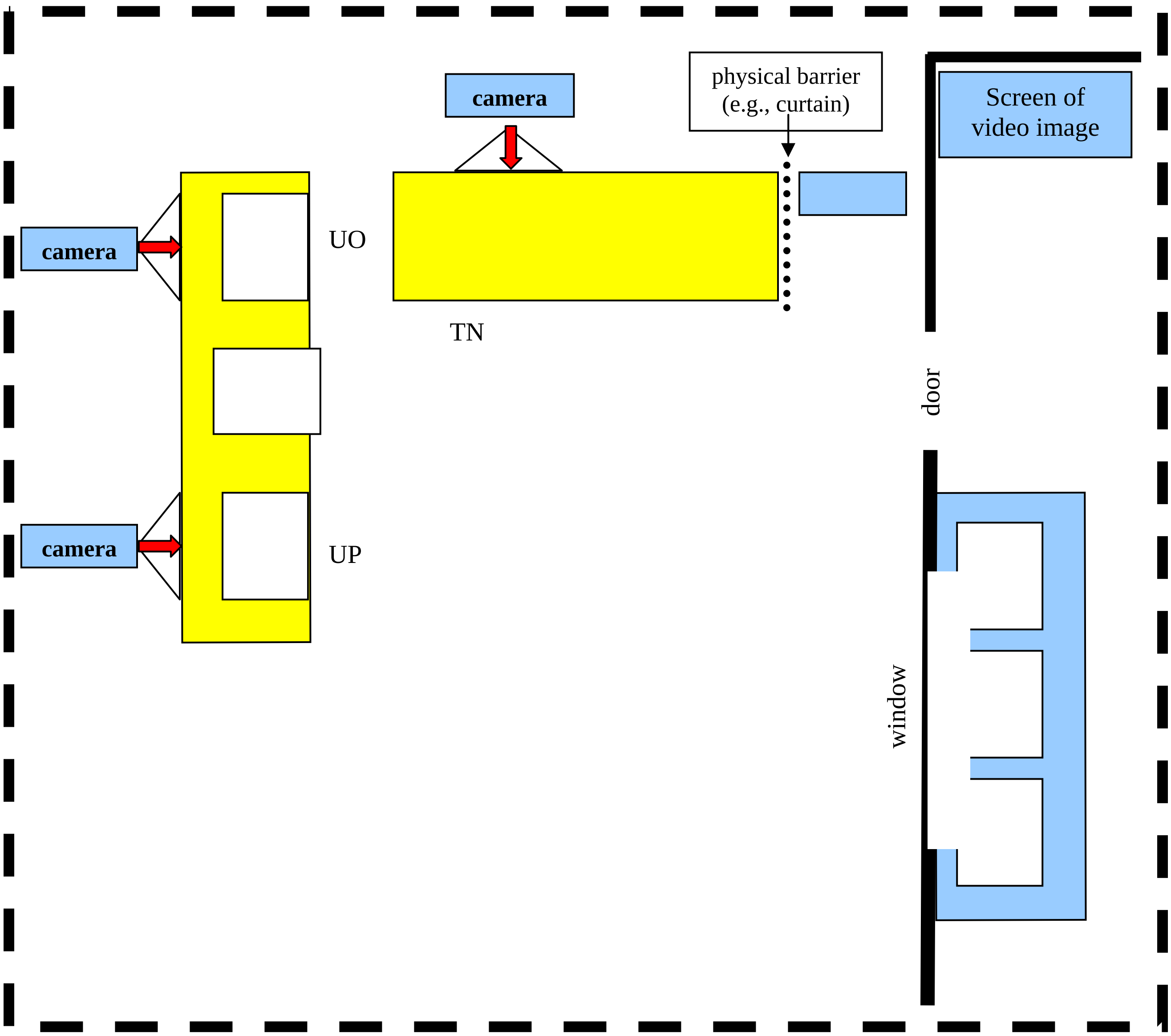

Figure A-1: Physical layout of the experimental environment

The STRIVE (manufactured by CAE) software was modified to support the concurrent control of multiple UAVs. It provides the simulations for all the UAVs and their sensor payloads. The visual databases and the entity models were also available to the multi-UAV scenario. The followings are some of the features of the simulation environment.

Video capture

Five video cameras will be positioned to capture critical crew actions and interactions, these include:

1. one camera set to capture hand movements of TN, UP, and UO;

2. as a minimum, one other camera to capture all crew interactions;

3. one camera to capture mission time recorded at 5 Hz (STRIVE time will be synchronized with mission time);

4. five feeds from subject displays (four displays and one STRIVE image) will be streamed to a video-scan conversion unit for recording; and

5. live video/audio data may be projected in a viewing area outside the simulation room to show images from video display console.

Audio capture

Intercom audio from both intercom nets must be recorded with audio and the video described above captured on same recorder, thus the audio will be time stamped as per video capture. An ambient microphone will be provided at all workstations. In addition, speakers or headsets will be located at experimenter station to play crew audio.

Mission time stamps

In accordance with the video capture, mission time will correspond to the time recorded on digital video recorder to allow collection of start and stop times for segments and critical task sequences. A mission clock will be provided, which will be set to 18:00 hrs at start of Part 1 of each mission, 18:20 hrs at start of Part 2, 18:40 hrs at start of Part 3.

A.3.9 Task and Procedure

The general task for the UAV crew is to run the scenario for searching terrorist vessel as quickly and accurately as possible. The experimental procedures will involve:

Day one:

a. welcoming the subject crew and introducing them to the experimental environment;

b. 10 minutes coffee break;

c. conduct of a training session for a set period of time (2 hours);

d. lunch

e. conduct of one mission, in three parts, with a qualitative data collection session following each part of the scenario and a 10 minute intermission;

Day two:

f. Welcoming (crew arrives)

g. 15 minutes coffee break;

h. conduct of the second mission, using the same procedure as the first mission; and

i. collection of qualitative comments.

A.3.10 Measurements

The main performance parameters include mission/segment completion time, response time for Critical Task Sequences (CTSs), and completion time for CTSs. CTS are those tasks identified by the previous hierarchical goal analyses as critical activities to take to achieve the overall counter-terrorist goal.

Hence, there are three objective performance and effectiveness measurements:

1. mission/segment completion time: the time subjects spend to complete the whole mission or any one of the segments,
2. critical task response time: the time subjects realize an critical event needs to react after it occurs, and
3. critical task completion time: the time subjects spend to finish a critical task once it is initiated.

Besides above objective measurements, there are two other subjective measurements: situational awareness and workload.

Situational Awareness: Subjective ratings of Situation Awareness (SA) are linked to the previous hierarchical goals of the crew member. Measures of SA uses a Situation Awareness Global Assessment Technique (SAGAT) technique at the end of each mission part. Using the SAGAT, the simulation will be frozen and the crew displays blanked. The UAV crew are then required to provide information regarding the current status of the various agents in the mission (e.g., status of a UAV asset, location and disposition of contacts) as well as information regarding the predicted future status of the agents (e.g., where the contact will be in 1, 5 10 minutes). The rating form is attached in Annex F.

Workload: Subjective ratings in the form of a modified NASA TLX will be used for assessing workload at the end of the experiment. The rating criteria are linked to the hierarchical goals of the UAV crew members. The rating form is attached in Annex F.

A.3.11 Data Collection

The data collection utility was developed to meet the specific experimental needs of this project. It is a relatively small software package that taps into available data from the scenario management tool (STRIVE) and specific data elements that are exported by the Graphic User Interface (GUI) software. It will name each data file based on crew number, mission number, part number, and IAI condition. In addition, automatically generated mission time records will be provided. The data files will include:

- mission time;
- operator (1=TN, 2=UP, 3=UO);
- keystroke (string) and PEP selections; and
- relevant scenario events initiated by experimentation staff.

The experimenter will be provided with an Excel-like spreadsheet (on a computer) for entry of start and stop times for each predetermined CTS. Mission times will be entered automatically when the experimenter selects the CTS label.

The STRIVE entity identification and location be recorded and time stamped. This will provide an ability to look at recorded site picture at any mission time. This entity record capability is required primarily when simulation has been paused. The status and crew's deployment and use of assets (e.g., UAV launch, sensor selections) will also be recorded.

A.3.12 Medical Screening

The subjects used for this experiment will be drawn from the CP140 user community (TN, NASO, Pilot and NAVCOM) and these members, who are "fit to fly", are considered medially suitable for operator interface experiments in this simulated CP140 tactical compartment. As a result, medical screening is not required.

A.3.13 Physician Coverage

The participants will not receive undue physical and/or mental stress due to participation within the study. No physician coverage is required for the study.

A.3.14 Roles and Qualifications of Team Members

The Test Team will be comprised of employees of CMC Electronics Human Factors Engineering Team and Carleton University Aviation and Cognitive Engineering (ACE) Laboratory. The Test Team will play the roles of STRIVE Operator (simulation setup and operation) and data collection. The CP140 subjects will operate as a crew and will be supplemented by a Test Team member who will play the role of NAVCOM. This person will be a serving member of the Maritime Proving and Evaluation Unit at CFB Greenwood.

The subject crew will be a trained coastal patrol crew and will respond to the pre-flight anti terrorist mission tasking. During the evolution of the experiment, the NAVCOM (who is a member of the experimental staff) will stimulate the subject crew will "taskings" from the

Operations Centre (MOC) at Maritime Forces Atlantic, in Halifax; and messages from other units such as the section of CF-18 fighters who join the scenario in the third part of the mission.

A.3.15 Risks and Benefits

Risks

This experiment is judged to be a minimal risk endeavor as the entire mission is “flown” in a synthetic environment located within the DND HEART TIES Laboratory in Ottawa. In that there are no risks associated with the experiment, a risk/benefit assessment is not required.

Benefits

The results from this study will increase the understanding of the impact of automated systems on the enhancement of CP140 capability, especially the integration with multiple UAV control systems on board.

A.3.16 Approximate Time Involvement

Each data collection session is anticipated to take two days, with the morning of the first day used for training and the rest of one and half days used for the six experimental runs (IAI ON and IAI OFF). Each day will be at least eight (8) hours long and it is expected that the test subjects will stay two or three nights in the Ottawa area.

A.3.17 Remuneration

No remuneration will be provided for involvement in this experiment as the test subjects are all serving members of DND. However, subjects’ travel expenses will be reimbursed by DRDC Toronto.

A.3.18 References

Artificial Intelligent Management and Development Corporation (AIMDC). A Generic Agent-Based Framework for the Design and Development of UAV/UCAV Control Systems. Defence Research & Development Canada Toronto Contract Report, CR 2004-062, 2004.

CMC Electronics. Hierarchical Goal Analysis and Performance Modeling for the Control of Multiple UAVs/UCAVs from Airborne Platform. Defence Research & Development Canada Toronto Contract Report CR 2004-063, May 2004.

Defence Research & Development Canada. (2002). Publication standard for scientific and technical documents. DRDC, Ottawa, Ontario.

Defence Research & Development Canada – Toronto (2002). Guidelines for Human Subject Participation in Research Projects. DRDC Toronto, Toronto, Ontario.

Hendy, K. C., Beevis, D., Lichacz, F., and Edwards, J. L. (2002). Analyzing the cognitive system from a perceptual control theory point of view. In, Cognitive systems engineering in military aviation environments: Avoiding cogminutia fragmentosa!: A report produced under the auspices of The Technical Cooperation Programme Technical Panel HUM TP-7 Human Factors in Aircraft Environments. Human Systems IAC, Wright-Patterson AFB, OH.

Hendy, K. C. & Farrell, P. S. (1997). Implementing a model of human information processing in a task network simulation environment (DCIEM 97-R-71). North York, Ontario, Canada: Defence and Civil Institute of Environmental Medicine.

Powers, W.T. (1973) *Behaviour: The control of perception*. New York: Aldine De Gruyter.

Annex B Pre-screening checklist

The following information will only be retained for the purposes of this study, and will not be disclosed to any other individual or organization.

Screening Questionnaire	Answer
1. Rank?	______________
2. Age?	______________
3. Gender?	Male ☐ Female ☐
4. Have you ever had experience in UAV control?	Yes ☐ No ☐
5. Have you ever had operational exposure to CP140?	Yes ☐ No ☐
6. What positions have you served on CP140 if you answer is Yes to question 5?	Pilot ☐ NAVCOM ☐ TN ☐ NASO ☐ ASO ☐ Other ☐________
7. Number of years of your experience in above positions?	______________
8. Estimated number of hours of your experience in above roles?	_______________
9. Do you have any difficulties seeing colour?	Yes ☐ No ☐

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Annex C Participants information package

Title of Experiment: Experimental Assessment of Intelligent Adaptive Interfaces for UAV

Principle Investigator: Dr. Ming Hou, DRDC Toronto

Run Director: Mr. Bob Kobierski, CMC Electronics Inc. (Ottawa)

Background: The primary mission when developing a product or system focuses on maximizing quality and minimizing cost. To accomplish this mission, products and systems are often developed via an iterative design cycle, which includes: research and development, definition of requirements and specifications, a concept/preliminary design, the development of a prototype, and experimental evaluation.

After the prototype is built, the design of the product or system is reviewed to gain feedback on the design. Specifically in this study, an experimental evaluation will be conducted to exam the efficacy of prototype intelligent adaptive interfaces for the control of multiple UAVs from an airborne platform. This is the last phase of DRDC three-year project: Advanced UAV Operator Interface Design, which will be performed by CMC Electronics Inc who is under contract with DND. Based on the results, recommendations and guidelines will be proposed for the design of advanced UAV operator interfaces.

Task: The participants in the study will be required to work together in front of a simulated UAV control unit which includes three control stations for UAV pilot, UAV operator, and TN. Through operator interfaces and associated input devices (e.g., trackball, joystick, keyboard, and PEP, etc.), these three individuals will work as a UAV crew to search and find a terrorist vessel in a counter-terrorist scenario near the East Coast. The scenario runs for about one hour with three parts and each part takes about 20 minutes. There will be two runs for the experiment. Upon completion of the experiment, the participants will be required to complete a debriefing session. Participant will be given a short break approximately every 20 minutes. There will be two experimental sessions, which are approximately sixty minutes in duration for each. The entire experiment will take about fifteen (15) hours including briefing, training, conducting trials, and debriefing. Participants are expected to stay in Ottawa area for two nights.

Benefits of this study: The results from the proposed study will increase the understanding of the impact of automated systems on the enhancement of CP140 capability, especially the integration with multiple UAV control systems on board.

Risks to Subject: No unusual risks are anticipated other than slight discomfort in posture, vision, eyestrain and possible headache.

Note: Participants are not expected to prepare for the test by inquiring other crews who have been involved in the previous study or by individual reading on the subject of this matter.

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Annex D Experimental instructions

The following briefing will be handed out to the participants as it appears in the participant information package (Annex B) and will also be explained by the experimenter to the prior beginning of the training session and experimental session.

The participants (you) in the study will be required to work together in front of a simulated UAV control unit which includes three control stations for UAV pilot, UAV sensor operator, and TN. Through operator interfaces and associated input devices (e.g., trackball, joystick, keyboard, and PEP, etc.), these three individuals (three of you) will work as a UAV crew to search and find a terrorist vessel in a counter-terrorist scenario near the East Coast. The scenario runs for about one hour with three parts and each part takes about 20 minutes. There will be two runs for the experiment. Upon completion of the experiment, the participants (you) will be required to complete a debriefing session. Participant (you) will be given a short break approximately every 20 minutes. Since there will be two experimental sessions, which are approximately one hours in duration for each, the entire experiment will take about fifteen (15) hours including briefing, training, conducting trials, and debriefing. Participants (you) are expected to stay in Ottawa area for two or three nights.

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Annex E Consent form

Protocol Number: L-511

Project Title: Experimental Assessment of Intelligent Adaptive Interfaces for UAV Operators

Principal Investigator: Dr. Ming Hou

I, ______________________________, hereby volunteer to participate as a subject in the study, "Experimental Assessment of Intelligent Adaptive Interfaces for UAV Operators". I have read the Protocol Briefing Form, and have had the opportunity to ask questions of the study facilitators. All of my questions concerning this study have been fully answered to my satisfaction. However, I may obtain additional information about the research project and have any questions about this study answered by contacting Dr. Ming Hou at (416) 635-2063 or Mr. Bob Koberiski at (613) 592-7400 x 2208

I have been told that I will be asked to participate in two experimental sessions, which is approximately sixty minutes in duration for each and 15 hours for the entire experiment including briefing, training, conducting trials, and debriefing.

I have been told that there are no unusual risks anticipated. I consider these risks acceptable. Also, I acknowledge that my participation in this study may involve risks that are currently unforeseen by the investigators.

I understand that I am considered to be on duty for disciplinary, administrative and Pension Act purposes during my participation in this study. This duty status has no effect on my right to withdraw from the experiment at any time I wish and I understand that no action will be taken against me for exercising this right. Furthermore, I understand that if my participation in this study results in a medical condition rendering me unfit for service, I may be released from the CF.

I have been advised that there will be no medical screening or physician coverage provided during my participation in the experiment.

I have been advised that the experimental data concerning me, and the video taken during my trials will be treated as confidential ('Protected B' IAW CF Security Requirements), and not revealed to anyone other than the investigators without my consent except as data unidentified as to source.

In the highly unlikely event of becoming ill during my experimental trial, I will go with the Investigators to seek immediate medical attention if either the Investigators or I consider that it is required. Every effort will be made to contact a family member or the designated person indicated below that will be necessary.

I understand that I am free to refuse to participate and may withdraw my consent without prejudice or hard feelings at any time. Will I withdraw my consent, my participation within the experiment will stop immediately.

I understand that for my participation in this research project will not be compensated for any stress allowance for each completed session. However, my TD expenses will be reimbursed by DRDC Toronto.

I have informed the Principal Investigator that I am currently a subject in the following other DRDC Toronto research project(s) ______________________________________ and/or that I am participating as a subject in the following research project(s) at an institution other than DRDC Toronto.

Volunteer's Name: ________________________________

Signature:____________________________ Date: ___________________________

Name of Witness to Signature: _______________________

Signature: ____________________________ Date: ___________________________

Family Member or Contact Person (name, address, daytime phone number & relationship

____

**Note:

<u>For military personnel:</u> All military personnel must obtain their Commanding Officer's signature designating approval to participate in this research project.

FOR SUBJECT ENQUIRY IF REQUIRED:

Will I have any questions or concerns regarding this project before, during, or after participation, I understand that I am encouraged to contact Defence R&D Canada - Toronto (PO Box 2000, 1133 Sheppard Avenue West, Toronto, Ontario, M3M 3B9). This contact can be made by surface mail at these addresses, or in person, by phone, or by email to any of the numbers and addresses listed below:

Principal Investigator

Dr. Ming Hou, (416) 635-2063, Ming.Hou@drdc-rddc.gc.ca

Chair, DRDC Human Research Ethics Committee (HREC)

Jack P. Landolt, Ph.D., (416) 635-2120, Jack.Landolt@drdc-rddc.gc.ca

I understand that I will be given a copy of this consent form so that I may contact any of the above-mentioned individuals at some time in the future will that be required.

Annex F Subjective measure rating forms

As noted above in the protocol, subjective ratings of performance are linked to the hierarchical goals of the crew member and will be obtained using 7-point scales (see format shown for SA ratings below).

Situational Awareness

Objective measures of SA include a SAGAT approach whereby the simulation is frozen and the screens are blanked at specific points in the mission. The UAV crew are then required to provide information regarding the current status of the various agents in the mission (e.g., status of a UAV asset, location and disposition of contacts) as well as information regarding the predicted future status of the agents (e.g., where the contact will be in 1, 5 10 minutes).

Subjective ratings of Situation Awareness will be obtained using 7-point scales. An example of a 7-point scale to index situation awareness of the UAV Pilot is as follows:

	SITUATION AWARENESS							
Awareness of:	very low			moderate			very high	
Each UAV location with respect to the CP140;	1	2	3	4	5	6	7	NA
Each UAV system status;	1	2	3	4	5	6	7	NA
The heading, altitude and airspeed of each UAV;	1	2	3	4	5	6	7	NA
Whether each UAV is undertaking the appropriate (most effective) tasking for the current situation;	1	2	3	4	5	6	7	NA
The current state of Terrorist Boat Classification or Identification;	1	2	3	4	5	6	7	NA

Workload Measure

As noted above in the protocol, a PDT may be used to obtain objective measures of workload. Subjective ratings in the form of a modified NASA TLX will be used. These rating forms will be tuned for each crew member and for each of the crew members' critical tasks. Since the relatively small sample size in this experiment, analyses of cross/inter-correlations are not justified and paired comparisons will not be performed.

RATING SCALE DEFINITIONS

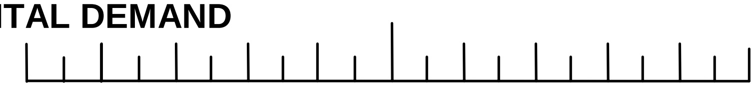
Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Instructions: Using the rating scales below and the definitions provided, mark each scale to indicate the degree of workload you experienced while completing the indicated task.

Operator: UAV Pilot

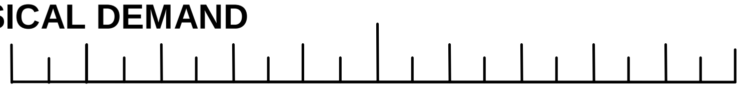
Task: Establish the Mini UAV in a position to allow the UAV Sensor Operator to use the EO suite to classify an unknown fishing boat.

MENTAL DEMAND



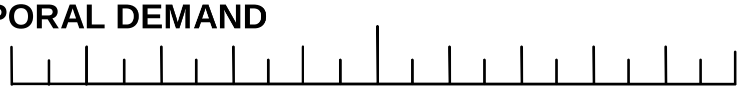
Low **High**

PHYSICAL DEMAND



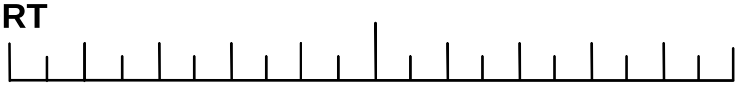
Low **High**

TEMPORAL DEMAND



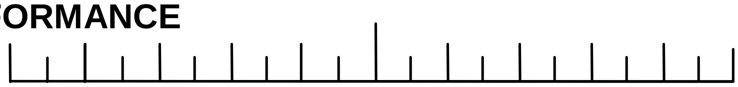
Low **High**

EFFORT



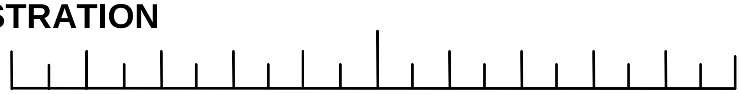
Low **High**

PERFORMANCE



Good **Poor**

FRUSTRATION



Low **High**

List of abbreviations

ANOVA	Analysis of Variance
CF	Canadian Forces
CFB	Canadian Forces Bases
CHOGM	Commonwealth Heads of Government Meeting
CTS	Completion Time for Critical Task Sequence
DMS	Data Management System
DND	Department of National Defence
DRDC	Defence Research & Development Canada
EO	Electro-Optic
GUI	Graphical User Interface
HGA	Hierarchical Goal Analysis
HUD	Heads-Up-Display
IAI	Intelligent Adaptive Interface
MALE UAV	Medium Altitude Long Endurance Uninhabited Aerial Vehicle
MH	Maritime Helicopter
MOC	Maritime Operations Centre
NATO	North Atlantic Treaty Organization
NAVCOM	Navigator Communicator
nm	nautical miles
OPI	Office of Primary Interest
PACT	Pilot Authorization and Control of Tasks
PEP	Programmable Entry Panel
PVI	Pilot-Vehicle Interface
R&D	Research & Development
RTB	Research Test Bed
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SE	Synthetic Environment
SME	Subject Matter Expert
STANAG	Standardization Agreement

TACPLOT	Tactical Plot
TLX	Task Load Index
TN	Tactical Navigator
UAV	Uninhabited Aerial Vehicle
UO	UAV Sensor Operator
UP	UAV Pilot
VTUAV	Vertical Take-Off UAV

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An absence of guidance on designing complex, dynamic, and networked systems presents challenges to the design of such systems to maximize overall human-machine system performance. An Intelligent Adaptive Interface (IAI) concept and associated technologies have been developed to address this problem. A typical IAI is driven by software agents that can change the display and /or control characteristics to react to the changes of mission and operator states in real time. The work reported here is the result of the two final phases of a three-year project conducted by DRDC Toronto. This project investigated the efficacy of IAIs in a multi-Uninhabited Aerial Vehicle (UAV) scenario. The IAI was modelled as part of the UAV tactical workstations found in a maritime patrol aircraft. In the first phase of the project, a performance model was developed to compare the difference in mission activities with and without IAI agent aids. The simulation results revealed that the control of multiple UAVs is a cognitively complex task with high workload. With the augmentation of automation agents, operators could continue working under high time pressure, resulting in critical tasks being achieved in reduced time. To further test the effectiveness of IAIs and validate the simulation results, a prototype IAI multi-agent experimental environment was implemented for an empirical study. Six IAI agent function groups have been integrated into the UAV operator interfaces. Operator’s performance was examined with and without IAIs under three different workload conditions. The results from both objective and subjective measures verified the findings of the simulation research. IAIs facilitated a significant reduction in workload and an improvement in situation awareness. This research also developed preliminary guidance on designing IAI systems.

Un problème qui se pose en ce qui concerne la commande de plusieurs engins télépilotés est la gestion de la masse d’informations nécessaires pour appuyer la prise de décision efficace. De l’avis des opérateurs d’engins télépilotés, l’amélioration des interfaces opérateur entraînerait des gains importants au niveau des performances et de l’efficacité des systèmes. Divers niveaux d’automatisation ont été suggérés pour résoudre le problème, dont l’utilisation d’interfaces adaptatives et intelligentes (IAI) pour l’aide à la décision. En dotant les postes de commande des engins télépilotés de groupes de fonctions d’automatisation, les IAI ont pour but de gérer l’information dynamiquement et de fournir la bonne information aux bonnes personnes au bon moment, pour appuyer la prise de décision efficace. Les travaux décrits dans le présent document sont l’aboutissement d’un projet de trois ans, réalisé par R & D pour la défense Canada, portant sur l’efficacité des IAI dans un scénario de commande de plusieurs engins télépilotés dans lequel les IAI sont modélisées comme faisant partie des postes de travail tactiques d’engins télépilotés à bord d’un avion de patrouille maritime. Un modèle de performance a été développé pour comparer la différence entre les activités de mission avec et sans automatisation, différence qui se reflète dans la fréquence des conflits de tâches et le temps d’exécution des tâches. Un prototype d’environnement expérimental d’IAI a été mis en œuvre pour une étude empirique à intervention humaine. Les résultats de la simulation et de l’expérience ont montré que la commande de plusieurs engins télépilotés est une tâche complexe sur le plan cognitif avec charge de travail élevée. Avec l’ajout d’agents d’automatisation, les IAI ont favorisé une baisse appréciable de la charge de travail et une amélioration de la connaissance de la situation. Les opérateurs peuvent continuer à travailler sous de fortes contraintes de temps, et des tâches critiques peuvent être exécutées en moins de temps qu’avec des interfaces classiques.

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